One Health

2nd Edition

The Theory and Practice of Integrated Health Approaches

Edited by
Jakob Zinsstag
Esther Schelling
Lisa Crump
Maxine Whittaker
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Craig Stephen

CABI

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A catalogue record for this book is available from the British Library, London, UK.

Library of Congress Cataloging-in-Publication Data

Names: Zinsstag, Jakob, editor.
Title: One health : the theory and practice of integrated health approaches / [edited by] Jakob Zinsstag, Esther Schelling, Lisa Crump, Maxine Whittaker, Marcel Tanner, Craig Stephen.
Other titles: One health (Zinsstag)
Description: 2 [edition]. | Wallingford, Oxfordshire, UK ; Boston : CAB International, [2020] | Includes bibliographical references and index. | Summary: “One Health has now expanded beyond discussion of emerging infectious diseases and zoonoses. Retaining its interdisciplinary focus, this new edition includes more non-infectious disease issues and climate change discussion alongside revised case studies and expanded methodology chapters to draw out implications for practice”-- Provided by publisher.
Identifiers: LCCN 2020024149 (print) | LCCN 2020024150 (ebook) | ISBN 9781789242577 (hardback) | ISBN 9781789242584 (ebook) | ISBN 9781789242591 (epub)
Subjects: LCSH: Communicable diseases--Prevention. | Public health.
Classification: LCC RA643 .O54 2020 (print) | LCC RA643 (ebook) | DDC 362.1969--dc23
LC record available at https://lccn.loc.gov/2020024149
LC ebook record available at https://lccn.loc.gov/2020024150

References to Internet websites (URLs) were accurate at the time of writing.

ISBN-13: 9781789242577 (hardback)
9781789242584 (ePDF)
9781789242591 (ePub)

Commissioning Editor: Alexandra Lainsbury
Editorial Assistant: Ali Thompson
Production Editor: Marta Patiño

Typeset by SPi, Pondicherry, India
Printed and bound in the UK by Severn, Gloucester

Contents

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Editors' Preface to the Second Edition

Five years after the publication of the first edition in 2015, we have the pleasure and possibility to produce a second edition of *One Health: the Theory and Practice of Integrated Health Approaches*. The present updated and largely revised version is motivated by the numerous, worldwide and most relevant activities in research and public health action aimed at implementing and carefully validating One Health approaches and also to make One Health a global public health reality. We are truly overwhelmed to realize how One Health thinking and actions have spread in near-epidemic dimensions. It is gratifying to see how the initial focus on zoonotic diseases expanded rapidly to encompass social and cultural dimensions, including transdisciplinary participatory approaches co-producing transformational knowledge between academic and non-academic actors like communities, authorities and the private sector, as a central element for negotiation of the required multilevel cooperation under the One Health paradigm.

One Health embraces the environmental and ecological dimension of health, fuelled by climate change, pollution, waste management crises, the dramatic decline of biodiversity and extinction of wildlife species and plants and therefore makes significant contributions to the global attempts of reaching the Sustainable Development Goals (SDGs). Non-communicable diseases, gradually and rapidly dominating the worldwide burden of diseases, extend the scope of One Health by their linkages to nutrition, food safety and security as well as mental and spiritual health, animal-assisted interventions and the human–animal bond.

Increasing antimicrobial resistance (AMR) globally raises serious health and economic concerns. The main drivers and determinants of the spread and subsequent colonization of resistant bacterial strains between humans, animals and the environment are still mostly unknown. AMR is therefore not only a quintessential One Health issue, but One Health is an essential prerequisite for a systemic understanding of AMR acquisition and spread and for identifying, developing and validating effective control strategies.

The current most illustrative example for the need for integrated approaches to health is the spread of the new coronavirus (COVID-19). It demonstrates the global systemic consequences of poorly understood animal–human interfaces, a butterfly effect,[1] in a likely zoonotic event which led to worldwide, serious economic consequences from reductions in trade and shortages of interconnected supply and production chains. Tragically, the prevailing shortsighted financial planning ignores the urgency of assessing the broader ramifications of public health and reduced funding for public health, particularly veterinary public health, an investment that would cost only a negligible fraction of the social and economic losses we witness today.

The insights gained from drastic examples like the recent COVID-19 epidemics along with the significant body of successful research and applications, as partly summarized in this second edition, encourage us ever more to insist on demonstrating the added value of integrated approaches and cooperation between related health sectors. It is only through integrative and iterative forms of cooperation that we can create the urgently required comprehensive policies to protect human and animal public health and preserve ecosystem services, a most powerful contribution to reduce and mitigate environmental and climate change.

It is an enormous pleasure for us to see the evolution of what initially appeared as a disconnected set of fragments and uncoordinated patchwork of thoughts, evidence and impacts to a coherent, well-profiled and unique quilt displaying an integrated view of health and well-being. The present edition attempts to carve out the key messages and to understand how scientific evidence can be translated into practices, academic teaching, institutional organization and integrated health policies resulting in a major impact in the pursuit to achieve the SDGs and, thus, better health and well-being within sustainable ecosystems.

We wish you a most stimulating read, and let us hope we can jointly tackle the remaining research, development and action agendas to which these contributions point. 'We are not only responsible for what we do, but also for what we do not' (Jean-Baptiste Poquelin, Molière, 1622–1673).

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29 February 2020

Note

[1] In chaos theory, butterfly effects are small initial changes, which result in large effects at a later stage (Henri Poincaré, Paris, 1854–1912).

Acknowledgements

We thank our editors at CABI, Alexandra Lainsbury and Ali Thompson, and CABI as a whole, for their most helpful support.

We gratefully acknowledge all external reviewers who contributed critical assessments to the different book chapters.

1 One Health in History

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Introduction

The purpose of this chapter is to outline the history of One Health. This task immediately raises the question of how to approach the history of a subject that only became known as 'One Health' a few years ago, and is still evolving conceptually under the influence of health challenges, scientific advances, and political, economic, environmental and professional priorities. While there were many precedents to One Health, they did not go by this term, and they occurred at times when health problems, scientific ideas, and the wider world were very different from today. This state of affairs makes it impossible to impose a simple structure on to past events, or to link them, in linear fashion, to present-day One Health.

It is important to highlight this problem because existing histories of One Health usually gloss over it. These accounts are structured around key historical figures and scientific advances, whose contributions to health are used to argue for the importance of pursuing a One Health approach today. The achievements of Rudolf Virchow, Robert Koch, William Osler, John McFadyean, James Steele and Calvin Schwabe are routinely celebrated, along with the health benefits of vaccination, the germ theory and zoonosis control. While the importance of these individuals and activities cannot be denied, their roles within the history of One Health require more critical consideration. The accounts in which they feature are neither politically neutral nor historically well grounded, and have been assembled not for the purpose of understanding the past, but for advancing the case for One Health today. While this strategy may be useful in justifying and winning support for One Health, it has resulted in an extremely partial and selective reading of the past.

Rather than analysing history retrospectively from the perspective of present-day agendas, this chapter adopts a neutral, prospective, evidence-based approach that pays due regard to historical context.[1] Drawing on an extensive body of historical literature and source material, it aims to effect a fundamental shift in the way that the history of One Health is popularly conceived. It takes as its subject matter the constellation of ideas, practices and circumstances that brought human and animal health (and to a lesser extent, the environment) into alignment, the people and institutions involved, and the reasons for change over time. Partly due to space constraints, and also because this history is still under active investigation, it makes no claim to completeness, particularly with regard to very recent events which are well described elsewhere (Lebouef, 2011; A. Cassidy, 2020, unpublished results). While Western medical and veterinary traditions form the primary focus, it acknowledges the importance of cross-cultural exchanges, which were often facilitated by international health organizations concerned with human and animal disease control.

The first section of the chapter analyses intersections between human and animal health in the premodern era, to reveal how deeply animals and animal health were embedded within human medicine. The second section extends from the late 18th-century foundation of the veterinary profession until the turn of the 20th century. It tracks the evolving relationship between the veterinary and

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medical professions, and how, as scientific ideas and practices changed, new links were forged between human and animal bodies and diseases. The third section extends this analysis into the 20th century, focusing particularly on the changing status of animals within medical research, and on international efforts to develop comparative medicine and veterinary public health. The conclusion reflects on the importance of these findings for history and for One Health today.

Pre-modern Connections

Looking back on the pre-modern era, commentators often highlight the existence of a fundamental, well-entrenched distinction between humans and animals, which derived from the Christian belief that only humans had souls (Hardy, 2003). In fact, this divide has been overstated, for the perceived boundaries between humans and animals were often blurred and unstable (Fudge, 2000). In health and medicine there historically existed three key points of intersection. First, animals were used to work out the anatomy and physiology of human bodies. Secondly, they were studied in comparison to humans in order to work out the relations between them. Thirdly, the theory and practice of animal medicine attracted the attention of human doctors, usually as an end in itself, but occasionally as a basis for comparison with human medicine. Aspects of these connections can be identified in very ancient civilizations (Gordon and Schwabe, 2004). However, as all three featured in ancient Greek thought, which exerted a powerful influence in the West right up to the 17th century, this will form the starting point of our survey.

Around one-quarter of the surviving works produced by the Greek philosopher Aristotle in the 4th century BC are devoted to animals, most importantly *History of Animals*, *Parts of Animals* and *Generation of Animals*. While Aristotle distinguished humans from animals through their possession of a rational soul, he also sought to relate them, by documenting differences and similarities in the form, function and purpose of their parts, and drawing up a taxonomic system. The numerous dissections he conducted in the course of this work illustrated the possibility of learning about humans from animals (Clutton-Brock, 1995). Taboos on the use of human bodies led the famous Greek doctor, Galen, working in 2nd-century Rome, to follow Aristotle's lead. In an extensive and influential body of writing he documented the results of his numerous observations and experiments on animals. The errors he made in extrapolating from animal to human anatomy were not discovered until Andreas Vesalius (1514–1564) revived human dissection at Padua University in the 16th century (Guerrini, 2003).

Vesalius, and several of his contemporaries and successors, also vivisected animals in their attempts to work out the differences between living and dead bodies, and to describe and explain how body parts functioned (Shotwell, 2013). Vivisection was problematic: debates surrounded the value of knowledge drawn from animals and the suffering involved (Guerrini, 2003). Nevertheless, it enabled Realdo Columbo (1516–1559) and Fabricius (1537–1619) to identify the pulmonary transit of the blood and the function of the venous valves, respectively. After studying under Fabricius, William Harvey took up an Aristotelian programme of research on animals that resulted in his novel and, at the time controversial, proposal that blood circulated. Meanwhile, as part of the wider investigation of nature, medical doctors followed Aristotle in dissecting dead animals, for example at the elite Paris Academy Royale des Sciences during the 1660s and 1670s. This activity, described as 'comparative anatomy', drew on animals derived from colonial conquests that were contained within European leaders' menageries (Cunningham, 2010).

The health of humans and animals, and their relations to the environment, were defined by the same medical theory: humouralism. Drawing on the ideas of Hippocrates and Galen, this formed the dominant system of medical thought until the 18th century. It held that all bodies were composed of four humours, influenced by factors such as feeding, climate, ventilation, exercise and sexual behaviour. Disease resulted from an imbalance between the humours (Curth, 2002). Bodily health was also influenced by changes in the environment, which the Hippocratic text, *Airs, Waters, Places*, held responsible for the rise and fall of epidemics (Wilkinson, 1992; Nutton, 2004). These ideas implied that similar interventions, such as bleeding, purging, lifestyle changes and improvements in the environment, could restore or maintain the humoural balance in both human and animal bodies. Formally trained healers usually focused on one or the other. Physicians, surgeons and apothecaries treated humans, while animals received dedicated attention from medieval veterinarians at the Mamluk courts, and from British farriers, French marechals, Spanish beitars and their equivalents in other countries (Conrad *et al*., 1995; Shehada, 2012). However, such healers were expensive and few in number. Consequently most humans and animals relied on self-help, clergymen, gentry, and the various self-styled healers that made up the 'medical marketplace'. Here, the division between species was less well defined (Curth, 2002).

The 17th and 18th century movement away from ancient Greek thought brought humans and animals into even greater proximity. The new experimental philosophy of nature, and Rene Descartes' (1596–1650) conception of animals as 'automata' (self-operating machines), resulted in the more extensive use of animal vivisection in medical research and teaching (Guerrini, 2003). For example, Swiss physiologist Albrecht von Haller (1708–1777) used live animals to work out human neurological functions (Eichberg, 2009). At Leiden in the Netherlands, and later in Edinburgh, Scotland, anatomy lecturers vivisected dogs and dissected humans simultaneously, in order to demonstrate to students the structure and the function of body parts (Guerrini, 2006). A new scheme of classifying animals, drawn up by Swedish naturalist, Carolus Linnaeus (1707–1778), placed humans, apes, monkeys and bats within the same order of primates, and brought humans and orangutans together in the genus *Homo*, thereby challenging notions of a human-animal divide (Ritvo, 1995). Subsequently, in Paris, additional classification schemes were drawn up using dissected animals from the Versailles menagerie. Here, the key figures were George Buffon (1739–1788), the medically trained comparative anatomist, Louis Daubenton (1716–1799), and Georges Cuvier (1769–1832) (Cunningham, 2010).

One of Daubenton's pupils, the physician Vicq d'Azyr (1749–1794), went beyond comparative anatomy to develop a truly comparative form of medicine. His initial concern was cattle plague or rinderpest. This disease was prevalent throughout Europe in the 18th century. It inspired much medical comment and attempts to control it by quarantine, modelled on responses to bubonic plague in humans (Wilkinson, 1992). After reporting upon this disease to the French government, d'Azyr was made secretary to a Royal Commission of Enquiry into epidemics and epizootics, and steered its 1778 evolution into the Societe Royale de Medicine. His investigations drew on medical meteorology and topology to correlate human and animal epidemics with climatic and geographical conditions. D'Azyr also performed animal experiments. He believed that by understanding the functioning of organs in health, it was possible to make sense of their dysfunction in disease (Hannaway, 1994). Perceiving no dividing line between human and animal medicine, he argued that 'considerations on the diseases which attack man are applicable without any exception to those which attack animals. Medicine is one: and its general principles, once set out, are very easy to apply to different circumstances and species' (Hannaway, 1977, p. 438).

A similar stance was adopted by a number of British surgeons, who became actively involved in equine health care during the second half of the 18th century. Arguing that 'physic' (conventional medicine) was the same whether practised on humans or horses, they wrote medicalized manuals of farriery and established infirmaries for the treatment of horses and tuition of pupils. For them, farriery was part of natural history or comparative anatomy. It was therefore a polite practice, suitable for a gentleman (MacKay, 2009).

Comparative anatomy was consolidated as a medical practice by the surgeon, John Hunter (1728–1793). He established his own menagerie, and spent hours each day dissecting and experimenting upon animals. He incorporated their bodies into his museum, which numbered over 500 species with 13,000 specimens at the time of his death in 1793 (Chaplin, 2008). Hunter's influence on the field of surgery and its growing profile kept animals at the forefront of medical research in subsequent years (Lawrence, 1996). It was one of his pupils, Edward Jenner, who showed in 1796 that cowpox inoculation could protect humans from smallpox (Fisher, 1991).

Enter the Vets

The connections outlined above reveal that in many ways, pre-modern medicine really was 'one'. So how did the creation of the veterinary profession impact this situation? The first schools were established in Lyon (1762) and Alfort (1777). By 1791 they existed throughout much of Europe: in Dresden, Freiburg, Karlsruhe, Berlin and Munich in Germany; Turin, Padua and Parma in Italy; as well as Vienna, Budapest, Copenhagen, Sweden and London (Cotchin, 1990). Historical accounts often portray their creation as a significant break with the past which led to a newly enlightened approach to animal healing (Wilkinson, 1992; Swabe, 1998). However, this interpretation is deeply flawed, for as shown above, animal bodies and their treatment in health and disease had already attracted substantial attention from medical doctors.

It is perhaps more accurate to view the veterinary schools as an expression of pre-existing medical interest in animals, because although circumstances varied from school to school, doctors often played important roles in driving and shaping veterinary education. The doctors' commitment to studying the health and medicine of animals is shown by the fact that they did not automatically cede this field to the new veterinary profession. Rather, as shown below, they intensified their investigations during the first half of the 19th century and drew on vets as collaborators. Therefore, although in time the connections between human and animal health lessened, this was not an immediate or inevitable consequence of the veterinary profession's formation (A. Woods, 2020, unpublished).

In the 1780s, against the wishes of founder Claude Bourgelat, the physician Vic d'Azyr refashioned the Alfort veterinary school into a research institution and assumed the chair of comparative anatomy. Teaching was extended to human fracture care and midwifery to enable vets to offer extended services in rural communities. For political reasons, these changes were reversed in 1788 (Hannaway, 1977, 1994). However, from the 1790s, a number of Alfort veterinary and medical staff (including Francois Magendie in the 1820s) engaged in the systematic vivisection of horses, making this one of the first contexts for development of experimental physiology in France (Elliott, 1987). The subsequent expansion of this field within Germany, France and, later in the century, to Britain (in the face of anti-vivisectionist opposition) considerably enhanced the use of animals as experimental tools within medicine (Bynum, 1994). For proponent Claude Bernard these uses were entirely justified, for 'to learn how man and animals live, we cannot avoid seeing great numbers of them die' (Bernard, 1957, p. 99).

In London, surgeons and (less commonly) physicians acted as governors for the Veterinary College (established in 1791), ran examinations for students, and were well represented on the student body: 130 surgeons had qualified as vets by 1830. Edward Coleman, principal of the College from 1796 to 1839, was also a surgeon, appointed on the strength of his research on animals and ability to teach farriery. He modelled veterinary education on that of human surgery. Veterinary students were encouraged to attend lectures in the London medical schools, while medical students had the opportunity to attend lectures on veterinary topics. However, little research was undertaken at the College. This drew criticisms from the medical press, which campaigned with disaffected vets for the reform of the school. In 1844, vets displaced doctors in the control of student examinations. Concurrently, reforms in medical education restricted the courses on offer. These shifts enhanced the institutional separation of the professions (A. Woods, 2020, unpublished).

However, as shown by the many reports on animal health issues that appeared in the medical press, doctors retained their interest in this topic, to the extent that veterinary surgeons sometimes accused them of stealing their patients. Doctors also conducted numerous investigations into animal disease pathology and epidemiology. Their infrequent use of the term 'comparative' to describe such investigations suggests that they regarded them as part of mainstream medicine. Their aims were to document animal diseases, to describe their analogies with human diseases, and to learn about the nature of disease in general. These investigations featured a remarkable and formerly unrecognized degree of collaboration between doctors and veterinary surgeons. Vets drew doctors' attentions to interesting cases and outbreaks, facilitated their access to live animals and dead bodies, and offered personal insights based on clinical experience. Less frequently, doctors assisted vets in their animal disease investigations. Grass-roots collaboration between the professions was therefore important to the development of mid-19th-century understandings of human and animal disease (A. Woods, 2020, unpublished).

Medical interest in animals was promoted further by two key scientific developments. First, investigations during the 1830s suggested that glanders in horses, rabies in dogs, and anthrax in animals were causally connected to the equivalent diseases in humans (Wilkinson, 1992). Secondly, there emerged a Romantic or philosophical form of comparative anatomy which suggested that humans and animals were formed on the same general plan. In their efforts to comprehend this plan, doctors compared the anatomy and pathology of the bodies and embryos of multiple animal species (Jacyna, 1984; Hopwood, 2009). Humans and animals were thereby brought together in ways that are usually attributed to Darwinism and the germ theory, 30 years later. This finding reveals that contrary to popular belief, the latter events did not spell a complete break with the past. Rather, they formed part of an ongoing process of making and remaking links between human and animal bodies, and diseases.

Veterinary education emerged later in North America than in Europe. While some of the earliest qualified vets were European émigrés, physicians were also extremely active. In the period 1820–1870 they investigated and reported on livestock diseases, campaigned for veterinary education, and established and taught at early veterinary schools that were mostly short lived (Smithcors, 1959). In 1863, Scottish vet Duncan McEachran founded the Montreal Veterinary College. Believing that veterinary medicine was a branch of human medicine, he modelled teaching on that of the McGill medical school. One of his best known collaborators was William Osler, a former student of Virchow's and lecturer in medicine at McGill, 1874–1884. Osler taught veterinary students, undertook research (mostly unpublished) into diseases of animals, and asserted the value of comparative medicine to medical audiences. Although today he is often heralded as a figurehead of One Health, he was not unusual at the time. His predecessors and successors at McGill also taught veterinary students, and several, such as J.G. Adami, produced more extensive and significant research in comparative medicine (Teigen, 1984, 1988).

Following the 1859 publication of Darwin's *Origin of the Species* which claimed that all living organisms descended by evolution from a common ancestor, some doctors attempted to trace the evolutionary history of disease by examining its manifestations in different animal species. The most famous participant was Eli Metchnikoff, whose Nobel Prize-winning theory of phagocytosis was inspired by evolutionary thinking (Tauber, 1994). Animal diseases were also important in the development of germ theories of disease. In Britain, their acceptance was precipitated by the devastating 1865–1867 epidemic of cattle plague, whose pathology and epidemiology was subjected to scientific investigation by medical doctors (Worboys, 1991). Elsewhere, seminal research on germs focused on the nature, prevention and spread of animal diseases. In France, Louis Pasteur produced vaccines against chicken cholera, anthrax and rabies. His German counterpart Robert Koch investigated anthrax and tuberculosis, as well as tropical animal diseases which inspired his concept of the carrier state.

Vets made important contributions to all these investigations, which used a myriad of animals for the purposes of research, diagnosis and the production of vaccines and sera (Bynum, 1990; Wilkinson, 1992; Gradmann, 2010). Existing aetiological connections between human and animal diseases were redefined in terms of germs. A new category of diseases, the zoonoses, emerged to incorporate these and parasitic diseases like trichinosis, for which the life cycle and spread via the meat trade were worked out from the mid-1850s to the 1870s by Virchow, among others. They formed the focus of a new field of veterinary public health (VPH).

Today, Darwinism, the discovery of germs, and the rise of bacteriology, are heralded as key events in the development of One Health approaches. Closer scrutiny, however, suggests that these events had the reverse effect. In redefining disease as the straightforward product of infectious agents invading susceptible bodies, they downgraded the importance of the environment to health (Worboys, 2000). In bringing human and animal biology closer together, they heralded changes – described below – in the epistemic status of experimental animals, from representatives of particular species to 'model' humans. In inspiring the mainstream adoption of the term 'comparative pathology', they marked the compartmentalization of animal disease from mainstream medicine, while the emergence of VPH resulted in a newly competitive relationship between doctors and vets over control of zoonotic diseases (Hardy, 2002; Waddington, 2006).

Medical and veterinary perspectives on zoonoses often differed because doctors prioritized human health, and vets prioritized health of animals and agriculture. In 1901 Robert Koch famously reversed his earlier opinion that human and bovine tuberculosis were not alike, adding to a climate of uncertainty about the nature, extent, or even existence of transmission pathways. Doctors and vets clashed over the health threats posed by meat and milk, the regulation of these foodstuffs, and how to define a healthy animal. The stakes were raised by Western governments' growing assumption of responsibility for health, and their increasing reliance on experts. Veterinary and medical disciplinary differences were given structural and political expression by their employment in separate government departments. Doctors generally had the upper hand, because their profession possessed higher status and had forged a public role years before the creation of state veterinary services. Throughout Europe and North America, dissatisfied vets organized and lobbied for state recognition and legal protection.[2] They gained some ground towards the end of the century, in inspecting meat at slaughterhouses and regulating the supply of hygienic milk. However, the nature and extent of these roles varied considerably between and within nations (Schmaltz, 1936; Koolmees, 2000; Hardy, 2002; Jones, 2003; Orland, 2003; Waddington, 2006; D. Berdah, London, UK, 2013, personal communication).

Animals and Humans in 20th-century Medicine

The 20th century was characterized by considerable ambiguity in the perceived relations between humans and animals in health and disease. This was particularly apparent in the status of animals within medical research, which underwent an important epistemological shift around the turn of the 20th century. Earlier, scientists had drawn on a diversity of species, including but not confined to earthworms, horses, birds, frogs, pets, zoo animals, horses, livestock and fish. They were usually familiar with these animals, having encountered them in farming, field sports, natural historical pursuits, zoos, and urban streets populated with horse-drawn transport, stray dogs, and livestock for sale and slaughter (Kete, 2007). The sheer ubiquity of animals made it easy to acquire them for experiment in life, and dissection after death. The resulting research was truly comparative. It sought to build general truths through examination of similarities and differences between animals. Acknowledging, with a nod to evolution, that species differences were to be expected, researchers did not assume that a finding was true of all animals until they had demonstrated it in a host of different species (Logan, 2002).

Subsequently, however, scientists moved away from demonstrating generality to presuming its existence. Animal diversity became a confounding factor rather than a research strength. It can be no coincidence that as towns grew larger, as animals disappeared from the streets and urban upbringings became the norm, scientists began to restrict their gaze to a handful of animal species that could be kept within the laboratory. Paralleling the rise of standardization and mass production within industry, scientists entered into the mass production of standardized laboratory animals whose features could be quantified or mechanically assessed. By the interwar period, with diversity reduced further through standardized husbandry and environments, these animals formed the mainstay of scientific work on cancer, genetics, and drug standardization. Their uses continued to expand throughout the second half of the century. By then, however, biomedical scientists were no longer engaging with them as animals, but as functional equivalents or 'models' of the human body whose scientific legitimacy was underpinned by the theory of evolution (Clause, 1993; Logan, 2002; Löwy, 2003; Rader, 2004; Kirk, 2008).

One interesting inversion of this state of affairs occurred in the context of veterinary medicine in the later 20th century. The increasing importance of human relationships with pets, and owners' greater willingness to invest financially in this relationship, resulted in the growing veterinary use of insulin treatment, orthopaedic surgery and transplant surgery. Originally these technologies were trialled on animal models before entering human medical practice. Now, their use in animal patients was informed by clinical trials and experiences in humans, who effectively became the models (Degeling, 2009; Gardiner, 2009; Schlich *et al*., 2009).

The increasing use of standardized animals within medical research caused some vets in Europe and North America to carve out a new role in caring for them. In the light of continuing public concerns about animal experimentation, they guided medical scientists on how to maximize experimental outcomes while minimizing animal welfare costs (Kirk, 2009). Such work was reminiscent of how vets had facilitated medical research on animal diseases during the mid-19th century, but the science, the setting and the animals were now very different. However, not all vets embraced the changing status of the laboratory animal. Starting in the 1920s, some voiced criticisms of animal models, and called instead for the study of spontaneous disease events in zoo, farm, wild and pet animals (Allbutt, 1924). They argued, as in the 19th century, that diversity was important to the creation of scientific knowledge, and they perceived disease problems in different species as analogous rather than identical. They referred to this form of investigation as 'comparative medicine' – although confusingly, the use of this term today applies to the care of laboratory animal models as well.

Interwar comparative medicine advocates included O. Charnock Bradley (1871–1937), Principal of the Royal (Dick) Veterinary College, Edinburgh, and T.W.M. Cameron, professor and Director of Parasitology at McGill University (Bradley, 1927; Cameron 1938a, b). Investigation of comparative medicine gathered momentum in the decades after World War II. Meetings at the New York Academy of Medicine, University of Michigan, Rockefeller Foundation, University of Pennsylvania and the London Zoological Society aimed to demonstrate its practical value and to debate its incorporation within medical, veterinary and graduate school curricula (Jones, 1959). In 1958, a joint Washington meeting of medical and veterinary experts attached to the World Health Organization (WHO) and the Pan-American Sanitary Bureau (PASB) proposed creation of a new programme in comparative medicine, with the aim of expanding the kinds of animals and animal diseases used in basic medical research (Smith, 1961). W.I.B Beveridge, Director of the Institute of Animal Pathology at Cambridge University, was the lead consultant (Beveridge, 1969). Initially concentrating on cardiovascular disease and cancer, the official task of this programme expanded in the early 1960s to include comparative virology, neuropathology and mycoplasmology, as well as work on the welfare of primates in medical research centres (Kaplan, 1961; Cotchin, 1962).

From the 1920s onwards, advocates of this form of enquiry adopted an almost identical refrain. They argued that comparative medicine could tackle a wider range of diseases than could be experimentally induced, and would produce fundamental insights common to all species. Although it required knowledge of species' similarities and differences, veterinary surgeons already possessed such insights. Moreover, the approach would help to bridge professional, epistemological and practical divisions between veterinary and human medicine (Bradley, 1927; Cameron, 1938a, b; Beveridge, 1972). Renewed calls for unifying veterinary and human medicine were made within this context, on the assumption that these were two strands of 'one' medicine.

Today, the coining of the term 'One Medicine' is usually attributed to Calvin Schwabe, a vigorous proponent of comparative medicine, who employed the term frequently in the third edition of his volume *Veterinary Medicine and Human Health* (1984). However, it was used on many earlier occasions to illustrate the nature and value of comparative medicine (Bradley, 1927, p. 129; Shope, 1959; Beveridge, 1969, p. 547). During the mid-20th century, it was particularly associated with authors from the University of Pennsylvania veterinary school (Schmidt, 1962; Allam, 1966; Cass, 1973) and the University of Minnesota.[3] It is likely that Schwabe adopted the term 'One Medicine' from mid-20th-century currents of thinking within comparative medicine.

By the 1970s the results of comparative medical research into chronic human disease were still rather uneven. It seems that the skills required for conducting this research were rather difficult to obtain, and that few scientists were convinced by its claimed superiority over other methods or by broader visions of 'One Medicine'. The failure to advance comparative medicine was indicative of the growing differences between the professions in their research orientation and in the status they awarded to animals. Such differences were consolidated by 20th-century research and development infrastructures, which allocated human and animal health to different funding streams, research institutions and international organizations.

Yet at the same time, certain individuals, working in specific settings on particular disease problems, brought human and animal health into closer alignment. One key institution was the Rockefeller Foundation, which made the study of animal pathology central to many of its medical, scientific and public health programmes (Corner, 1964). Theobald Smith, the first director of its Department of Animal Pathology at Princeton (established in 1915), had made his name at the Bureau of Animal Industry, where he applied a comparative ecological approach to the study of Texas fever (Méthot, 2012). Both he and his successor, Richard E. Shope, who discovered the influenza virus of pigs and proposed its role in human influenza, were medically trained. Yet they saw animal pathology as the necessary foundation of *all* medicine (Shope, 1959). One particularly productive line of work, begun by Peyton Rous on chickens and continued later on rabbits in collaboration with Shope, was the role of viruses in cancer causation (Rous, 1910; Shope, 1933). Elsewhere in the USA, the University of Pennsylvania, the Mayo Clinic at the University of Minnesota (incorporated in 1915) and the Hooper Foundation for Medical Research at the University of California (established in 1913) were among a cluster of institutions that supported medical–veterinary interactions in research and postgraduate education (Steele, 1991). In France and Germany, the Pasteur and Koch institutes remained committed to a comparative approach, as did other medical research centres in Europe (Gradmann, 2010). In Britain, the Medical Research Council established a programme of research into dog distemper which helped scientists to discover the human influenza virus in 1933 (Bresalier and Worboys, 2014).

Twentieth-century relations between health and the environment were similarly characterized by variability and ambiguity. By enabling the targeted control of infectious agents, the development of vaccines and antibiotics diverted attention away from the environmental factors that influenced their emergence, spread and clinical impacts. These interventions were so successful in the West that despite a few opposing voices, by the 1960s and 1970s it was widely believed the conquest of infectious disease was in sight (Anderson, 2004). In certain colonial and post-colonial settings where infectious diseases remained a problem, however, the environment could not be ignored. In the case of trypanosomiasis during the first half of the century, a highly ecological set of investigations resulted which drew on entomology, medicine, veterinary medicine and agricultural science to generate a dynamic picture of the disease (Tilley, 2011).

The elevation of development as an economic and political priority made colonial and post-colonial settings important to the integration of human and livestock health and nutrition (Staples, 2006). In 1948, as part of an international drive to improve human health through disease control and better nutrition, the WHO set up a VPH unit within its Division of Communicable Diseases (WHO, 1958). Headed by the American Martin Kaplan, who had degrees in veterinary medicine and public health, it developed close relations with the Food and Agriculture Organization of the United Nations (FAO), other UN agencies, and the Office International des Epizooties (OIE) (Kaplan, 1953). A series of joint WHO/FAO meetings in the 1950s led to collaborative programmes on zoonoses, meat hygiene and veterinary education. It also brought a working definition of VPH as comprising 'all the community efforts influencing and influenced by the veterinary medical arts and sciences applied to the prevention of diseases, protection of life, and promotion of the wellbeing and efficiency of man' (WHO/FAO, 1951).

In framing animal health as a crucial problem of human health and development, the FAO and WHO positioned veterinarians, trained and working within public health, as vital to realizing these goals (Bresalier, 2018). However, most countries lacked such personnel (WHO/FAO, 1956), therefore establishing new education and training programmes became a key focus. Through the 1950s and 1960s, the WHO and FAO acted to support and fund veterinary and VPH education in the developing world. These activities relied on expertise drawn from the USA, which led the post-war development of VPH at national, state and local levels, as well as internationally through the Pan-American Health Bureau (PAHB). The leading figure in these initiatives was James H. Steele (Steele, 2008). Trained in both veterinary medicine and public health, he was a prodigy of the Swiss-American veterinary pathologist Karl M. Meyer, himself a vocal proponent of the integration of human and animal medicine. It was Meyer who established the Hooper Foundation as a world-leading research centre on zoonoses and food safety.

As is evident from the above, post-colonial and international health contexts were very important in shaping the careers and ideas of many of the key figures who aligned themselves with a 'One Medicine' agenda. Their work within developing countries also enabled them to engage in cross-cultural encounters and exchanges with pastoral and agricultural peoples, which informed their thinking about the relationship between human and animal health, disease and medicine (Kaplan, 1966; Green, 1998; Beinart and Brown, 2013). The influence of these experiences and contexts can, for example, be detected in Calvin Schwabe's frequently cited work, *Veterinary Medicine and Human Health* (Schwabe, 1964, 1969, 1984). More generally, this history indicates that many of the roots of present-day One Health lie in earlier currents of veterinary thought and practice that were deeply entangled with projects of development, international health, aid and post-colonial reconstruction.

Conclusion: From One Medicine to One Health

In analysing the changing relations between the health of humans, animals and the environment, this chapter demonstrates the many and varied links between them. Human medicine, in particular, has a rich history of engagement with animals, their diseases, and the people and institutions dedicated to animal health. Correspondingly, since the late 18th-century creation of their profession, vets have supported, collaborated and sometimes competed with this medical programme. These interconnections can be explained, in part, by reference to prevailing scientific ideas, practices and disease problems, but they can only be fully understood by examining the people involved, their institutional settings, and the wider professional, political, economic and environmental contexts. The historical specificity of these factors, as well as the variability of the health activities they influenced, makes it impossible to construct a simple, linear narrative linking past to present. Nor is it possible to draw direct lessons from history, or to claim – as do many existing histories – that the work of certain historical figures demonstrates the importance of pursuing One Health today.

This does not mean, however, that the past is irrelevant to the present. One key finding to emerge from this account is that links between the health of humans, animals and the environment were often investigated at grass-roots levels in the course of everyday veterinary and medical science and practice. For the most part, these activities were not articulated into a definite agenda of 'comparative pathology', 'comparative medicine', 'veterinary public health' or 'One Medicine'. Only at certain historical junctures did practitioners choose to adopt these terms, usually in order to validate or win wider support for operationalizing their activities. Pushing beyond these labels and the rhetoric that surrounded them and looking at what was actually happening on the ground reveals that integrated approaches to health were much more widespread and more significant than previously realized. It is no understatement to say that health and medicine today are heavily shaped and underpinned by the many precursors to One Health.

One Health itself, as a self-consciously labelled set of activities and agendas, has emerged very recently out of a complex and rapidly shifting coalition of international health bodies, veterinary associations, academic advocates, environmental organizations and pharmaceutical companies. While its history has been fully explored elsewhere (e.g. Lebouf, 2011; Chien, 2013; A. Cassidy, 2019, unpublished), this chapter concludes by sketching out the broad contours of these developments in order to put the rest of this volume into context.

During the 2000s, elements of the ongoing traditions of comparative medicine and VPH came together into a rearticulated vision of 'One Medicine, One Health'. This involved the alliance or convergence of veterinary and human medical research and/or clinical practice, including collaborative research, and shared clinics, vaccination strategies, equipment and drug development (e.g. King *et al*., 2008). In parallel, a different (albeit overlapping) set of actors and agendas came together around the term 'One World, One Health'™ (OWOH). In contrast to the veterinary–medical focus of One Medicine, OWOH tended to address a broader range of disciplines across the life and environmental sciences while maintaining a relatively tight focus on issues such as 'emerging infectious diseases'. The idea of 'One World' (OW) has its origins in mid-20th-century debates about international relations and the formation of the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Sluga, 2010). It was significantly taken up by health actors during the 1990s, when the global scale and potential wildlife origins of the human immunodeficiency virus (HIV)/acquired immune deficiency syndrome (AIDS) pandemic were recognized (Whiteside, 1996; King, 2004). In 2004, the first of a series of meetings between human public health, conservation and infectious disease experts was organized by the US-based Wildlife Conservation Society on the theme of OWOH. The idea then found strong purchase in international responses to the outbreak of highly pathogenic avian influenza (HPAI), and was adopted by the WHO, FAO, OIE and others in a shared statement of cooperative intent (FAO *et al*., 2008) following the HPAI crisis (Scoones and Forster, 2008; Scoones, 2010).

Through the 2000s, these two sets of agendas became increasingly intertwined, and since the end of the decade they have increasingly shared the broader, snappier and more widely used banner of 'One Health' (Zinsstag *et al*., 2005; FAO *et al*., 2010). The recent adoption of the language of One Health by key organizations across the worlds of veterinary and human medicine, international health and other agencies, national governments and research funding bodies, represents the integration of these various agendas. Advocates, based particularly in the USA and Switzerland, have organized workshops, conferences, reports, websites and journal publications to promote it. As an organizing concept, it has proved flexible enough to encompass very different languages, ideas and working practices, yet coherent enough to enable communication across disciplinary and organizational divides (Lebouef, 2011; Chien, 2013). However, questions remain about the long-term viability, practical utility, sustained interdisciplinarity and persistent anthropocentrism of One Health (Lee and Brumme, 2013; Bardosh, 2016; Cassidy, 2016; Manlove *et al.*, 2016; Kamenshchikova, 2019), as well as how it can productively engage with questions of colonial and post-colonial legacies, power, and ongoing tensions between local and 'global' approaches to health (Scoones, 2010; Green, 2012; Beinart and Brown, 2013; Yates-Doerr, 2015; Cunningham *et al.*, 2017; Rock *et al.*, 2017).

Like its predecessors, the rise of One Health cannot be explained solely by advocacy, internal scientific logic, or as the natural and inevitable outcome of long-standing efforts to bring humans, animals and the environment closer together. A product of 21st-century concerns, it forms part of a wider cluster of research and policy agendas, including 'food security', 'biosecurity', 'global health' and 'translational medicine', which also aim to break down barriers between disciplines. Intriguingly, each of these addresses issues relevant to, or even overlapping with One Health, but is oriented towards a different group of disciplines (e.g. 'food security' tends to appear in the environmental and agricultural sciences.) Rather than competing for resources or legitimacy, these agendas may instead be mutually reinforcing. Jointly, they could be described as part of a collective response to a (re)-emerging set of highly complex concerns which extend across traditional disciplinary boundaries – over environmental damage, climate change and scarce resources, food availability and disease/health (Bardosh, 2016; Cairns and Krzywoszynska, 2016; Cassidy, 2016; Felt *et al.*, 2016; Harrison *et al.*, 2019; Senanayake and King, 2019) and finally, how animals contribute to shape modern medicine (Cassidy *et al.*, 2017; Woods *et al.*, 2018; Kirk *et al.*, 2019; Koch, 2019; Schoefert, 2019). This is the arena in which the future of One Health will be forged, but in looking ahead, we should not forget its multiple historical precedents, and their influence on the present.

Notes

[1] For another balanced historical perspective on this topic, see Kirk and Worboys (2011).

[2] Numerous papers on this topic were delivered to the 2012 Congress of the World Association for the History of Veterinary Medicine. For a summary see Woods (2012).

[3] Today Pennsylvania Vet School has its own trademarked slogan, 'Many Species, One Medicine'™, attributed broadly to another 19th-century 'founding father', Benjamin Rush MD (Hendricks *et al.*, 2009).

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2 Why One Health?

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One Health: Benefits from Closer Cooperation

The convergence of interests in human and animal health, based on careful observation and scientific study, has a long history which has gained attention from medical historians in the last few years (Woods *et al.*, 2018). Much of this convergence is based on inferences and analogies from empirical observations of specific diseases and comparative anatomy rather than on broader definitions of health (Bresalier *et al.*, Chapter 1, this volume). Among the many proponents of a closer interaction of human and animal health (Zinsstag *et al.*, 2015), two are particularly noteworthy: (i) Rudolf Virchow, the founder of cellular pathology in the late 19th century; and (ii) Calvin Schwabe (Box 2.1), an internationally renowned veterinary epidemiologist and pioneer of veterinary public health in the 20th century. Virchow and Schwabe were among the first to articulate key points that motivated elaboration of the premise of One Health. Discussing bovine tuberculosis (Tschopp and Yahyaoui, Chapter 22, this volume) at a hearing in the Prussian senate, Virchow stated: 'There is no scientific barrier between veterinary and human medicine, nor should there be. The experiences of one must be used for the development of the other'[1] (Bollinger, 1902; Saunders, 2000). Influenced by his experience of working with Dinka pastoralists in Sudan, Schwabe coined the term 'one medicine', to make the point that 'There is no difference of paradigm between human and veterinary medicine. Both sciences share a common body of knowledge in anatomy, physiology, pathology, on the origins of diseases in all species' (Schwabe, 1984).

Indeed the methods of comparative medicine used in both human and veterinary medicines are closely related and have produced – and continue to produce – enormous mutual benefits. Most therapeutic interventions in human medicine were developed and tested in animals. Under the increasing influence of specialization, however, human and veterinary medicine diverged, and too often fail to communicate, even when they share interests in the same disease. For example, during a recent outbreak of Q-fever in the Netherlands, public health authorities were not informed by veterinary authorities about a wave of abortions in goats (Enserink, 2010). Similarly, outbreaks of Rift Valley fever in humans in Mauritania were identified as yellow fever by mistake. The correct diagnosis was made only after public health services contacted livestock services and learned about the occurrence of abortions in cattle (Digoutte, 1999; Schelling *et al.*, 2007a).

Collaborations between veterinarians and physicians should produce benefits that are broader than merely additive. The beyond-additive value-added benefits are related to direct positive outcomes not just in reduced risks and improved health and well-being of animals and humans, but also in financial savings, reduced time to detection of disease outbreaks and subsequent public health actions, as well as improved environmental services (Zinsstag *et al.*, Chapter 31, this volume). For example, a mixed team of doctors and veterinarians examining human and animal health in mobile pastoralist communities in Chad found that more cattle were vaccinated than children. None of the children were fully vaccinated against childhood diseases. Recognition of this fact enabled subsequent joint

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Box 2.1. Calvin Schwabe 15 March 1927–27 July 2006 (Zinsstag and Sackmann, 2007).

Calvin Schwabe graduated with a zoology degree in 1948 and obtained his doctorate in veterinary medicine in 1954. At Harvard, he obtained a master's degree in public health and a PhD in parasitology and tropical medicine (1956). For 10 years, Schwabe worked at the American University in Beirut. His main interests were parasitic diseases, mainly echinococcosis. He initiated control programmes and led the WHO expert committee on veterinary public health in Geneva. In 1966, he became a full professor in veterinary epidemiology at UC Davis (California). Schwabe's interests reached far beyond health issues towards more integrated approaches to science. His overarching views on health of all species influenced modern concepts of veterinary public health, One Health and ecosystem health. His vast bibliography is accessible at: https://oculus.nlm.nih.gov/cgi/f/findaid/findaid-idx?c=nlmfindaid;idno=schwabe (accessed 27 March 2020).

human and animal vaccination campaigns providing preventive vaccination to children who would otherwise not have had access to health services. Clearly, a closer cooperation of veterinarians and doctors generated a better health status than what could have been achieved by working in isolation (Schelling *et al*., 2007a; Häsler *et al*., Chapter 10, this volume; Danielsen and Schelling, Chapter 14, this volume). Such joint services are scalable to national and regional level by adopting a systems strengthening perspective leading to an extension from Calvin Schwabe's concept of 'one medicine' to One Health (Zinsstag *et al*., 2005). This has been clearly validated as a public health concept in different areas of the world, ranging from Africa to Asia (Zinsstag *et al*., 2011).

Today, One Health has become a broad international movement supported by the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO) and the World Organisation for Animal Health (OIE). The World Bank produced a first account of economic aspects of One Health (World-Bank, 2010, 2012), which can include health consequences of structural aspects such as political change (Roth *et al*., 2003) or globalized agriculture (Wallace *et al*., 2015). In the USA, a One Health commission coordinates and assembles many of the activities ('www.onehealthcommission.org' (accessed 27 March 2020)).The European Cooperation in Science and Technology (COST) funded the creation of a Network for Evaluation of One Health (NEOH), which developed an evaluation framework (Rüegg *et al*., 2017) and coined the term 'One Health-ness'. One Health-ness is expressed as a mixed method index of quantitative and qualitative operational and infrastructural aspects of One Health. NEOH includes environmental, ecosystem and structural elements of health, and connects to the Sustainable Development Goals (SDGs) of the United Nations (Rüegg *et al*., 2017, 2018; Hitziger *et al*., 2018).

One Health has thus gained broad recognition as an integrated approach to health when compared with mainstream reductionist approaches in the health sciences. Yet, by expanding the integration of health towards broad social-ecological issues like antimicrobial resistance or deforestation, complex interactions can become 'wicked' and hardly tractable.

Rüegg and co-workers state: 'There is a need to provide evidence on the added value of these integrated and transdisciplinary approaches to governments, researchers, funding bodies and stakeholders' (Rüegg *et al*., 2018). We thus recall the foundational principles of One Health:

1. One Health is about *cooperation* between different academic disciplines underlying human and veterinary medicine in the first place, but without any barrier to natural and social sciences and the humanities. One Health also engages with non-academic actors in the co-production of knowledge (Berger-González *et al*., Chapter 6, this volume).
2. Cooperating partners will seek a benefit of working together sooner or later. To fully understand the range of potential benefits of a closer cooperation implies a deeper and comprehensive recognition and understanding of how humans and animals and their environment are interrelated at all scales. This is a necessary requirement of One Health but still not sufficient.

A sufficient requirement for One Health is demonstrating the benefits and added values resulting from the crosstalk and closer cooperation between human and animal health and all related disciplines and stakeholders.

We thus define One Health as any added value in terms of health of humans and animals, financial savings, social resilience and environmental sustainability *achievable by the cooperation of human and veterinary medicine and other disciplines when compared to the two medicines and other disciplines working separately.*

The equal focus on the health of people and animals is one of the characteristics that has differentiated the organization, strategy and practice of One Health from several other related fields, such as veterinary public health, resilience, ecohealth, and most recently, planetary health (Horton *et al*., 2014; Pongsiri *et al*., 2019). The latter two consider ecological resilience and sustainability more prominently (see more discussion on this below; also Bunch and Waltner-Toews, Chapter 4, this volume; Lerner and Zinsstag, Chapter 5, this volume).

Based on these characteristics, the challenge is to show how, through highly iterative processes and actions, both directly and indirectly, physicians serve animal health and veterinarians serve public health. We need methods that are capable of quantitatively and qualitatively measuring interactions at the interface of human and animal health. Such methods have been developed for survey design (Schelling and Hattendorf, Chapter 8, this volume), integrated surveillance and response (Aenishaenslin *et al*., Chapter 9, this volume), economics (Häsler *et al*., Chapter 10, this volume), animal-to-human transmission of infectious diseases (Chitnis *et al*., Chapter 12, this volume) and integrated health services (Danielsen and Schelling, Chapter 14, this volume). The postulate of an added value of such a closer cooperation is summarized in Zinsstag *et al*. (Chapter 31, this volume).

Cultural Differences in Human–Animal Relations and their Implications

Dealing with human and animal health as One Health inevitably sheds light on the human–animal relationship and bond. Domestication of wild animals was one of the fundamental cultural achievements of humans, and the use of animals for hunting and as livestock was critical for human development and culture. One Health, even in a more restricted definition as offered here, faces challenging questions regarding cultural differences in view of animals and how they are valued. Thus One Health should reflect on the normative aspects (values) of the human–animal relationship with emphasis on improving animal protection and welfare (see also Wettlaufer *et al*., Chapter 11, this volume; Hediger and Beetz, Chapter 26, this volume; and Fries and Tschanz Cooke, Chapter 27, this volume). Secondly, even if ecological resilience or health is not the primary outcome of concern, One Health implies an interface of humans and animals with the environment, which can be highly complex, requiring systemic approaches to the physical and social environment. They relate human and environmental systems and are also called social-ecological systems (SES). SES relate to theory of complexity (Ostrom, 2007). Thirdly, One Health empirical experience involves not only human and animal health professionals but also reaches out to many other academic domains, as well as to non-academic actors like public and private institutions, authorities, civil societies, communities and households. It engages with the public in a transdisciplinary way, considering all forms of academic and non-academic knowledge for practical problem solving at the animal–human interface. The strongest leverage of One Health is observed when it is applied to practical societal problem solving (Berger-González *et al*., Chapter 6, this volume).

Normative aspects of the human–animal relationship

Similarly to the human–human relationship, the human–animal relationship is governed by norms and values determined by culture and religion. Animals are regarded as intimate companions with a high emotional value or simply as prey with a financial value for their meat. Humans are also valued as prey by animals under certain circumstances. This is certainly one of the reasons for deep-seated fears against wildlife, which have led to the extinction or threat of extinction of predators in large parts of the world (White *et al*., Chapter 3, this volume; Bunch and Waltner-Toews, Chapter 4, this volume). There is no biological reason why humans should not consider their surrounding domesticated animals and wildlife as close relatives and treat them with utmost care. Currently, on the one hand, globalized livestock production maximizes profits with little regard for humane standards towards animals. At the same time, moderate intensification of livestock production is a way out of the poverty trap for millions of smallholder farmers. On the other hand, we observe very close relationships with companion animals, to the point of humanizing them and considering them as family members. Although not adhering to any of the more dogmatic and naturalist-populist moves, with promotion of person rights to primates and whales, we must recognize that animals cannot be considered as commodities without certain rights. We refer the reader to the growing literature on the moral status of animals and animal welfare (Wettlaufer *et al.*, Chapter 11, this volume). More recently and controversially, these considerations have been extended to arthropods (Waltner-Toews and Houle, 2017).

Ancient Egyptians saw humans and animals as 'one flock of God', and contemporary Fulani express similar views in their creation myths in West Africa (Sow, 1966). Medical knowledge in India is influenced by beliefs about metempsychosis and reincarnation between animals and humans. According to various schools of Hindu spirituality, there is no distinction between human beings and other life forms. All life forms, including plants and animals, possess souls, and humans can be reborn as animals and vice versa. Such thinking greatly influences how animals are perceived and handled. Comparable to Hinduism[2] and Jainism, in Buddhism, as little harm as possible is done to animals. Buddhists treat the lives of human and non-human animals with equal respect (Ryder, 1964; Cowell, 1973; Sangave, 1991). Judeo-Christian traditions focused less on spiritual kinship than on the moral and empirical responsibilities of humans towards other animals. Biblical texts report that humans and terrestrial animals were created on the same day, and the Sabbath regulations also imply the resting of livestock, indicating a strong co-creational attitude in the Judeo-Christian Bible. In the Qur'an, animals are considered close to humans. Modern animal welfare has roots in southern German pietism, and here we cite Albert Schweitzer, inspired for his philosophical idea of 'reverence for life', or in the original German language: 'Ehrfurcht vor dem Leben'. In summary, the contemporary human–animal relationship is polarized between merciless exploitation of livestock and humanizing of pets. Within the dilemma of aspirations of a globalized economy, social development and animal welfare, culture and religion as well as economic considerations largely influence the human–animal relationship and subsequently the potential of a closer cooperation of human and animal health.

Working in different cultures to achieve One Health outcomes implies adopting the view that there are multiple legitimate perspectives and that practices must be adapted to local contexts. We need to clarify both our own perspective and point of view. Adopting a *self-reflexive attitude*, we may ask, 'What is the personal cultural/religious background driving my animal–human relationship?' Our own attitude towards animals influences how we value animal life economically or emotionally. For example, the dogs in Fig. 2.1A have a market value for consumption of approximately US$12 in a local market in West Africa, whereas the pet cat in Fig. 2.1B is part of a household in Europe, with a willingness to spend a considerable amount of money on veterinary care. Consequently, when we report about our research from One Health studies we also need to explain the *perspective* (i.e. the social, cultural and religious background, from which the animal–human relationship is seen) as it strongly determines the valuing in economic frameworks and societal contexts (Zinsstag and Weiss, 2001; Narrod *et al.*, 2012). The overarching approach in practising One Health, however, clearly ought not to be driven by any specific perspective but rather by the pragmatic approach,

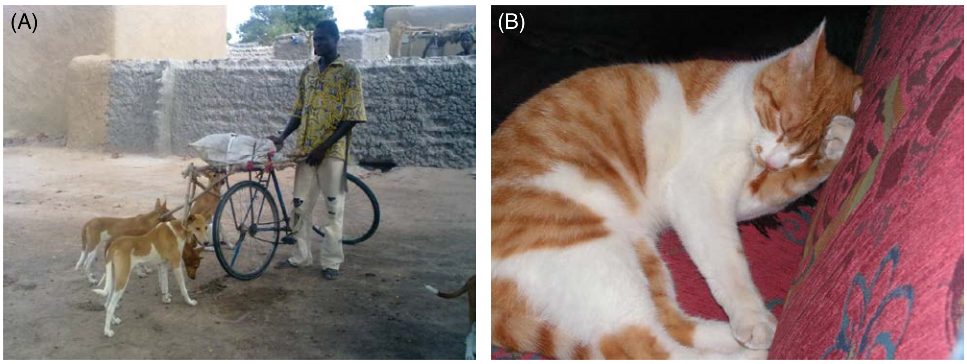

Fig. 2.1. A dog trader on his way to the market in Eastern Mali, West Africa (A) and pet cat in a household in Switzerland (B). Photos courtesy of J. Zinsstag.

which effectively brings together resources from different disciplines and resources to address the priorities of the concerned human and animal populations.

One Health and animal ethical and welfare issues

A One Health perspective also encompasses reflections on human and animal well-being per se. Humans have rights and seek to maximize their well-being. Similarly, one might ask, if animals have rights, how do we consider their well-being (Wettlaufer *et al*., Chapter 11 this volume)? Despite an overall protective attitude in most cultures and religions, the reality is often appalling. Worldwide, and across different cultures and religions, millions of animals are reared, transported and slaughtered under terribly inhumane conditions, urgently calling for much stronger engagement on animal protection and welfare.

Animal biodiversity contributes to stable ecosystem services, and extensive livestock rearing maintains carbon sequestration in semi-arid areas. Animal disease threatens human health and food security, for example through transmission of zoonotic diseases or loss of animals for ploughing. Large parts of the world could not be inhabited without the use of livestock in a moderate way. Consequently, we can no longer close our eyes to the close linkage, interrelations and interdependencies of human and animal health without considering simultaneously maintenance of stable ecosystem services, some of which are seriously threatened by livestock rearing methods and/or excessive human exploitive activities.

Peter Rabinowitz, an occupational physician at Yale University proposed that humans should change their point of view towards animals from an 'us versus them' to a 'shared risk' attitude between humans and animals (Rabinowitz *et al*., 2008; Rabinowitz and Conti, 2010). As an example, we can consider the high cancer rate of beluga whales in the Saguenay Fjord in Canada. Belugas are continually exposed to industrial and other human-derived wastes. The beluga cancer incidence has become an indicator of environmental quality. Humans therefore have an interest in preserving the quality of the environment in a state that does not adversely affect both whale and human health.

From an integrative One Health, conservation biology and/or an ecosystem perspective, animals should be much better valued and treated as part of an overall effort to maintain and sustain ecosystem integrity and, thus, comprehensive well-being. This involves, among other things, animal husbandry and rearing, animal transport, slaughter practices, animal traction and wildlife conservation (see White *et al*., Chapter 3, this volume; Bunch and Waltner-Toews, Chapter 4, this volume; Wettlaufer *et al*., Chapter 11, this volume).

Globally, most livestock holders treat their animals well. In Fig. 2.2 we observe a nearly unrestrained type of animal husbandry. The horse being milked by the Kyrgyz lady stands still without being tied. Similarly, the camels and donkeys in Ethiopia are calm and obviously well treated. However, animal welfare is clearly insufficient in semi-intensive and intensive production systems. Livestock holders should be continuously trained on best animal welfare practices in their rearing systems. From an animal welfare perspective, the current practice of transporting livestock on foot, say from Ireland to France for slaughter, is not acceptable. Similarly, in developing countries, small ruminants and poultry are transported hundreds of kilometres under congested conditions, often without water, and sometimes severely beaten. Slaughtering practices should aim to reduce stress during animal handling. As part of economic growth, meat consumption has grown massively in the last decades. Livestock plays an important role especially in the livelihoods of hundreds of millions of small-scale farmers. However, ruminant livestock production contributes to the emission of greenhouse gases, and reduction of ruminant meat consumption is part of the overall strategy to avert climate change (Gordon *et al*., Chapter 25, this volume).

Animals are also, one might say mostly, used in agriculture in developing countries for ploughing, transport and traction of carriages. While cattle and camels used for ploughing or transport are usually well treated, there is undeniably huge suffering in horses and donkeys used for transport. Donkeys are among the worst-treated animals worldwide and urgently need better treatment and husbandry. There is increasing research on livestock, companion animals and wildlife in developing countries. However, there is almost a complete lack of legislation on animal testing. Care should be taken that animal testing is not exported from industrialized countries to evade stringent regulations. We should not forget the welfare standards for pets, which may similarly undergo huge suffering.

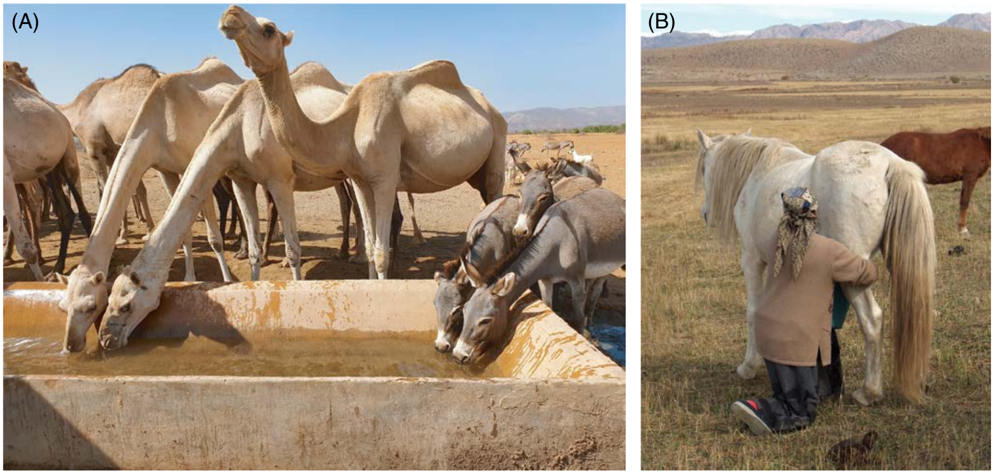

Fig. 2.2. Camels and donkeys in Ethiopia (A) and a woman milking a horse in Kyrgyzstan (B). Photos courtesy of J. Zinsstag.

For example, dogs and cats are often abandoned at the beginning of the summer holidays, so that owners do not have to care for them.

From a One Health perspective, the notion of burden of disease should be extended to animals to reflect the toll of life and suffering of humans and animals, for example in road traffic, which causes hundreds of thousands of wildlife deaths. Road safety should then be expressed as causing this number of human and this number of animal casualties. Modern highway planning effectively protects animal life by utilizing fencing, bridges and tunnels for safe animal movement. While animal lives can be counted, estimating animal suffering and disability, similarly to human burden measures like the disability adjusted life year (DALY), is hardly possible because of the variation of norms and values across cultures and production systems. For example, how would expected years of life for male calves or fattening pigs be adequately assessed? There is an ongoing and controversial debate, but still not enough research undertaken, in development of a combined metric of human and animal disease burden. The recent introduction of the zDALY, an adjusted indicator to estimate the burden of zoonotic diseases, is controversial because it puts a monetary value on human life depending on local purchasing power (Torgerson *et al.*, 2018; Häsler *et al.*, Chapter 10, this volume). Improving animal welfare remains a permanent challenge to any effort and ethical aspiration of One Health (Wettlaufer *et al.*, Chapter 11, this volume).

One Health as embedded in landscapes

One Health as presented here is not an isolated idea. There are earlier more limited and also broader concepts. We should mention Evgeny Pavlovsky's (1884–1965) concept of disease nidality. He considered pathogens from an ecological perspective having their own ecological niche. This might be a specific space in an ecosystem or an animal or organ to which they are most adapted. For example, marmots in Mongolia carry *Yersinia pestis*, the agent of plague, without symptoms. Occasionally, marmot hunters become ill with plague after handling marmot carcasses.

Calvin Schwabe met Evgeny Pavlovsky in Leningrad in 1965 and wrote in his memoirs:

> The only noteworthy work-related event in Leningrad was my meeting with Eugene Pavlovsky, the dean of the Soviet descriptive epidemiologists, formal developer of medical ecological notions like 'landscape epidemiology' and 'natural foci of infections'. … He had read *Veterinary Medicine and Human Health* [(Schwabe, 1984) reference added] already and said he was pleased to see an American author write on the 'Ecological Study of Disease', which was my title of the 1st edition chapter introducing epidemiology.
>
> (C. Schwabe, unpublished)[3]

More recent examples of landscape–disease interactions include the ways in which emerging diseases, such as those associated with West Nile virus and *Borrelia burgdorferi*, are related to urban landscape design (Waltner-Toews and Waltner-Toews, 2017).

One of the most prominent interactions of human and animal health is veterinary public health (VPH), which is defined as the contribution of veterinary medicine to public health. VPH is well established in international organizations, governmental administrations and academia. VPH was originally conceived by the Centers for Disease Control in Atlanta by James H. Steele. Schwabe refers to it as 'the innovative Veterinary Public Health Unit founded by Jim Steele, ... helping to demonstrate the value of an organised and systematic capability for disease intelligence' (C. Schwabe, unpublished)[4].

Compared to One Health, VPH mainly serves public health. Conceptually, it does not consider a mutual benefit from public health for animal health.

A much broader concept is an 'ecosystem approach to health' or 'ecohealth'. Ecohealth considers inextricable linkages between ecosystems, society and health (Rapport *et al.*, 1999). It seeks in-depth understanding of ecological processes and their relation to human and animal health. For example, using an ecohealth approach it was demonstrated that mercury poisoning of fish and impending health risks for humans in the Amazon were not due to upstream gold mining but due to soil erosion following deforestation (Forget and Lebel, 2001). Ecohealth has become an internationally scholarly movement organized by Ecohealth International.[5] Ecohealth is a systemic approach, tackling complex problems as embedded in non-linear systems dynamics quantitatively and qualitatively. It involves transdisciplinary approaches, connecting academic and non-academic knowledge in a mutual learning process. It includes all stakeholders from communities to authorities as actors in the research process, pays particular attention to gender and social equity and thrives to put knowledge into action through policy change, interventions and improvement of practices (Charron, 2012). Hence, One Health is embedded in and an integral part of the ecohealth concept (Zinsstag, 2012).

Knowledge and information in veterinary and medical sciences are growing continuously, with the consequence that we know more and more about progressively narrower subjects. The ongoing and accelerated fragmentation of veterinary and medical science is not conducive to complex problem solving, and we face an increasing risk for misinterpretation, for example, in comparative diagnosis and pathology (Cardiff *et al.*, 2008; Zinsstag *et al.*, 2009). Mainstream reductionist research seeks to explain phenomena at an increasingly smaller scale. On the other hand, major current challenges, like development of antimicrobial resistance in a complex environment, call for rethinking modern theory of health of animals and humans. One Health provides the respective conceptual grounding and operational outlook.

There are signs of convergence in various fields in systems biology, the social sciences and networks of ecological scholars such as the Resilience Alliance[6] (Zinsstag *et al.*, 2011). The interactions of humans, animals and the environment are not straightforward. They are part of human-environment systems or SES. SES are, in the words of economist Elinor Ostrom, complex, multivariable, non-linear, cross-scale and changing (Ostrom, 2007). Humans and animals are inextricably linked to ecological systems, both natural and manmade, called cultural and social systems. Biomedical health sciences need to interact with all scholarly pursuits related to social systems, like sociology, economy, political sciences, anthropology and religion. Similarly, they need to interact with ecology, geography and all environment-related sciences. All these processes span across scales, like from molecules to populations. Health can be considered as an outcome of SES and so we speak about health in social-ecological systems (HSES) (Fig. 2.3). HSES clearly transcends One Health conceptual thinking as defined above. Considering health as an outcome of SES relates to theory of complexity and systems theory (Bertalanffy, 1951). Attempts to understand health in complex systems can be regarded as processes generating unexpected and new phenomena (described by the term 'emergence').[7] Currently, we are exposed to a number of unintended and poorly understood damages to natural resources and life support systems, like climate change or nuclear catastrophes, which cannot be tackled by normal reductionist scientific approaches. Normal expert knowledge is no longer sufficient in situations of high uncertainty as we have experienced in the recent past and well postulated in writing about 'post-normal science' (Bunch and Waltner-Toews, Chapter 4, this volume). Planetary health aspires to demonstrate linkages of global change and health (Horton *et al.*, 2014; Pongsiri *et al.*, 2019).

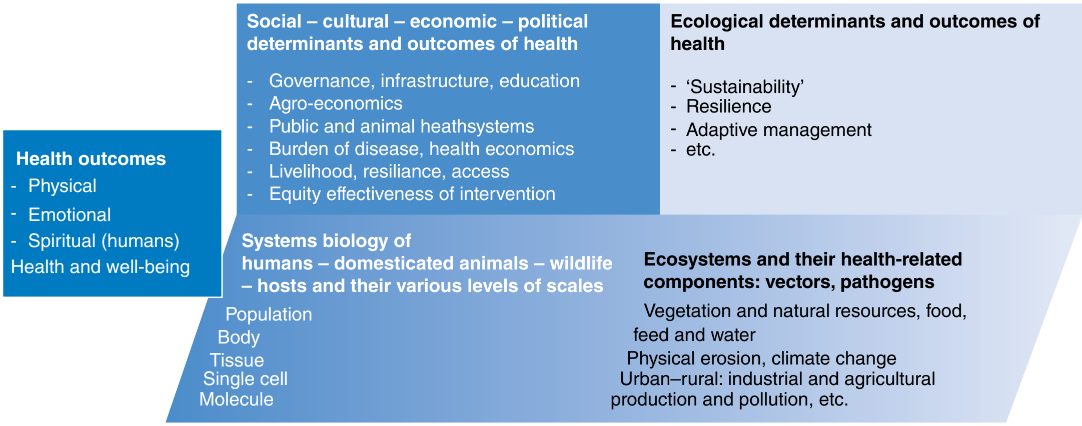

Fig. 2.3. Health in social-ecological systems (HSES).

One Health and transdisciplinarity

As developed in the previous section, One Health is a scientifically established and validated concept that also created a movement with its origins in management of disease threats to humans and animals (Zinsstag, 2012). During development of health services and zoonoses control in developing countries, scientists engaged with communities, authorities and other stakeholders (Danielsen and Schelling, Chapter 14, this volume; Léchenne *et al.*, Chapter 19, this volume). Periodic communication of research findings by scientists to all stakeholders, such as local communities, peripheral health workers and public health and VPH practitioners, led to more integrated research processes, assuring validity, social relevance and translation for impact. As a consequence, mutual trust increased gradually. Progress in One Health research can clearly benefit from combining academic and non-academic knowledge in the search for improving health and access to health care for humans and animals in pastoralist communities (Schelling *et al.*, 2007b). Engagement of science with non-academic stakeholders and knowledge is a form of 'transdisciplinary' research, as a further development of 'interdisciplinary' approaches, which usually combine different academic disciplines such as medicine and social science, but do not encompass non-academic stakeholders. Mittelstrass defines 'transdisciplinarity' as a form

Box 2.2. Summary of theoretical issues of One Health.

One Health can be defined as any added value in terms of health of humans and animals, financial savings or environmental services achievable by the cooperation of human and veterinary medicine when compared with the concepts of approaches of the two medicines working separately.

- One Health inevitably sheds light on the human–animal relationship and bond. It should reflect on the normative aspects (values) of the human–animal relationship with emphasis on improving animal protection and welfare in an inter-cultural context.
- One Health engages with the public in a transdisciplinary way, considering all forms of academic and non-academic knowledge for practical problem solving at the animal–human interface. The strongest leverage of One Health is observed when it is applied to practical societal problem solving.
- One Health approaches are embedded into 'ecohealth' conceptual thinking, which are further expanded to 'health in social-ecological systems' (HSES) addressing complex issues of human-environment systems.

of research that transcends disciplinary boundaries to address and solve problems related to the life-world (Hirsch Hadorn *et al.*, 2008). Transdisciplinarity clearly matches the concept of 'post-normal' science, as discussed above (Hirsch Hadorn *et al.*, 2008; Bunch and Waltner-Toews, Chapter 4, this volume; Berger-González *et al.*, Chapter 6, this volume).

In conclusion, One Health represents a harmonic development of traditional VPH within the context of transdisciplinarity and post-normal science, challenged by the situation of our planet that is threatened by the overwhelming demands of populations of people, companion animals, livestock and wildlife (Box 2.2). As such, it raises questions that encompass conventional understandings of comparative medicine but go far beyond this into the intense, unstable and complex interactions among culture, economic aspirations and ecological sustainability. The interactions over time from which health emerges are embedded in narratives that reflect the concerns of the scholars and political leaders who espouse them. These narratives clarify points of disagreement and conflict but also suggest possibilities, if not for resolution of conflicts, then at least as avenues for accommodating multiple perspectives (Waltner-Toews, 2017).

Notes

[1] Original citation in German 'Es gibt keine wissenschaftliche Barriere zwischen Veterinär- und Humanmedizin, noch sollte es eine geben; die Erfahrung der einen muss gebraucht werden für die Entwicklung der anderen' (Saunders, 2000).
[2] Protocol for handling animal welfare cases in cooperation with the Hindu community. Available at: http://archive.defra.gov.uk/foodfarm/farmanimal/welfare/documents/hindu-protocol-0812.pdf (accessed 27 March 2020).
[3] Calvin Schwabe, Hoofprints of Cheiron, Book two, page 262 unpublished memoirs.
[4] Calvin Schwabe, Hoofprints of Cheiron, Book two, page 223 unpublished memoirs.
[5] https://www.ecohealthinternational.org/ (accessed 27 March 2020).
[6] https://www.resalliance.org/ (accessed 27 March 2020).
[7] Such thoughts can be traced to process philosophy (Alfred North Whitehead). Causal inference is limited and processes appear as random events. At best, we can understand partial processes.

Acknowledgement

Thank you to Mitchell Weiss for critical comments about the manuscript and providing references to Asian literature.

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3 An Ecological and Conservation Perspective

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Introduction

Natural ecosystems are facing unprecedented threats that directly threaten human, animal and environmental well-being through decreases in critical ecosystem services (IPBES, 2019). The top five drivers causing the largest global impacts to biodiversity and ecosystem services include: (i) changes in land and sea use; (ii) direct exploitation of organisms (e.g. hunting and fishing); (iii) climate change; (iv) pollution; and (v) invasive alien species (IPBES, 2019). Although One Health acknowledges the link between the health of humans, animals and the environment, One Health discussions have historically focused on the prevention and control of infectious disease at the human–animal interface rather than these large-scale drivers of health. While One Health has succeeded in bringing awareness to the need for proactive disease control measures such as strengthened biosecurity and vaccine development (Roth *et al*., 2003; Zinsstag *et al*., 2009; Middleton *et al*., 2014; Machalaba *et al*., 2018), disease is only one component of health. In this chapter, we explore the potential for One Health to shift its focus from disease prevention to health promotion to more fully integrate solutions that protect the health of humans, animals and the ecosystems on which we all depend for our economies, livelihoods, food security and health. This shift would facilitate a more seamless inclusion of ecological health and environmental conservation in the One Health paradigm and can serve as the basis for a comprehensive approach to complex problems at the root of global health. A framework for creating and applying health metrics for wildlife and ecological systems is essential for measuring the success of actions aimed at maintaining or shifting systems to desired states.

The focus on disease in One Health

In the late 20th century the number of human infectious disease outbreaks increased globally (Smith *et al*., 2014). These outbreaks included a resurgence of diseases such as cholera, tuberculosis and viral gastroenteritis (Morse, 1995; Smith *et al*., 2014) and the emergence of diseases such as severe acute respiratory syndrome (SARS), bovine spongiform encephalopathy and Ebola heamorrhagic fever (Karesh and Cook, 2009). Many recent emerging pathogens were discovered to have animal origins (Jones *et al*., 2008), and their occurrence and spread were either directly or indirectly facilitated by humans. Through increasing global travel and trade, microbes began to rapidly traverse the globe (Morse, 1995). Infections such as SARS, which originated in small carnivores in Asia, spread via a hotel visitor to five continents in a matter of weeks (Karesh and Cook, 2009) and solidified the idea among the public health community that emerging zoonotic diseases could be a significant threat to global human health.

At a New York symposium in 2004, international health experts developed what became known as

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the 'Manhattan Principles on One World One Health' (Cook *et al.*, 2004). These principles emphasized the need for 'interdisciplinary and cross-sectoral approaches to disease prevention, surveillance, monitoring, control, and mitigation as well as to environmental conservation more broadly'. At a 2004 summit in Mexico City, Mexico the need for integration of human and animal health systems under the concept 'one medicine' was also proposed (Zinsstag *et al.*, 2005). Although this was not the first time that interdisciplinary approaches to combating disease had been proposed, international support and continued emergence of new zoonotic diseases gave the One Health concept more widespread momentum and acceptance. For the next decade, the One Health community increased political and public awareness of the role of animals in disease emergence and brought about new investments such as the US Agency for International Development's PREDICT programme, which focuses on wildlife most likely to carry new emerging infectious disease threats to humans. International collaborations such as the Global Early Warning System also formed to detect and assess health threats and emerging risks at the human–animal–ecosystems interface (FAO–OIE–WHO, 2019).

Prevention and control of diseases that traffic between wildlife populations, people and domestic animals have been, and will continue to be, important endeavours, particularly wildlife-associated infectious diseases with public health implications and pathogens at the wildlife–livestock interface. For example, elimination of fox rabies in Europe reduced rabies risk to humans and domestic animals (Freuling *et al.*, 2013). On-farm biosecurity for poultry premises will continue to be important to prevent avian influenza transmission between wild birds and poultry (Lee *et al.*, 2018). Efforts to prevent human diseases spilling into wildlife have also been important for maintaining endangered great ape (*Hominidae*) populations (Gilardi *et al.*, 2017).

Despite its importance, prevention and control of infectious disease will not be sufficient to combat the myriad health effects caused by global forces such as climate change and loss of biodiversity and ecosystem integrity. A health-centric perspective acknowledges the importance of disease as one factor among many that influence the health of humans and animals (see Box 3.1). Scientists often gravitate towards reductionist approaches because observing a single component (e.g. disease) is simpler than trying to observe the entire system. However, the health effects of current One Health challenges, such as climate change loss of ecosystem function, will exceed the impacts of their effects on disease emergence and spread. The complexity of these issues will likely require a systems approach (Zinsstag *et al.*, Chapter 2, this volume) to identify the multitude of drivers (including human values), their interrelationships and feedback loops, so that effective solutions and policy changes can be found (Table 3.1) (Zinsstag *et al.*, 2011).

Box 3.1. A systems approach to conservation: black-footed ferret case study.

Black-footed ferrets (*Mustela nigripes*) are one of North America's most endangered mammals. A major impediment to survival of this species is sylvatic plague (caused by the bacterium *Yersinia pestis*) as both ferrets and their major food source, prairie dogs, are highly susceptible to this disease. Due to the importance of this disease, sylvatic plague is one of the few wildlife diseases for which a vaccine has been developed and field tested. A combination of the vaccine and insecticides to reduce flea populations that carry the plague bacteria are used to control plague outbreaks on the landscape (Roth, 2019). Although disease management will be essential for survival of black-footed ferrets, it is not the only strategy needed to ensure their recovery. Ferret reintroduction efforts are also impeded by factors such as eradication of prairie dogs in some parts of their native range as they are considered agricultural pests (Casper *et al.*, 2018). Human values such as landowner views of prairie dogs as pests will be critical to address to ensure the long-term recovery of ferrets.

Human, animal and ecosystem health

A shift in focus from a reductionist disease-centric view to a systems-oriented, health-centric model requires a common understanding of what falls under the umbrella of 'health'. Human health has been variably defined as 'freedom from disease' (Boorse, 1977), 'ability to perform valued social roles' (Stokes *et al.*, 1982), 'complete physical, mental, and social well-being' (WHO, 1948) and 'capacity to adapt, respond to, or control life's challenges' (Frankish *et al.*, 1996). One reason that the definition continues to evolve is that health is not an objective state, but rather a construct dependent on

Table 3.1. Depending on the type of health-related issue, different approaches may be needed to address them. With a disease-centric approach the goal is often disease prevention or mitigation. Systems-oriented health-centric approaches focus on solutions that promote health for which disease prevention or mitigation is only one component. This table illustrates One Health issues associated with either a disease- or health-centric approach.

Disease-centric approach	Health-centric approach
Pathogen spillover and spillback dynamics	Landscape change and habitat fragmentation
Prevention of diseases	Securing needs for daily living (e.g. food and water security) (Gordon *et al*., Chapter 25, this volume)
Eradication of pathogens	Climate and environmental change (Zinsstag *et al*., 2018; Stephen *et al*., Chapter 17, this volume)
Risk factors for diseases	Community resilience capacity
	Joint health-care provision to remote populations (Schelling *et al*., 2007; Häsler *et al*., Chapter 10, this volume)

human ideas and values (Hanisch *et al*., 2012; Lerner and Zinsstag, Chapter 5, this volume). When defining animal health, the value and function of the animal in relationship to humans plays a role. For instance, the criteria used for evaluating the health of a pet dog, valued for companionship, will be different from those used when considering the health of a dairy cow, valued for production. Similarly, for wildlife, ideal survival rates, reproduction rates, or disease prevalence in a population will be determined by human values and are likely to differ for an endangered species compared with a nuisance species as well as among stakeholder groups (e.g. wildlife enthusiasts, animal rights activists, tourism facilities, livestock farmers, land managers and land owners).

Considering health as the capacity of populations to cope with change (Stephen, 2014) emphasizes characteristics that affect vulnerability and resilience (Obrist *et al*., 2010; Zinsstag *et al*., Chapter 31, this volume) and could be used to fortify health in the face of uncertainty rather than waiting to address hazards after they emerge (Stephen, 2016). In wildlife as in humans, capacity to cope with change is influenced by interacting biological, social, societal and environmental determinants. As such, health can be assessed indirectly by assessing these determinants, including hazards, such as disease, and promoters, such as biodiversity and habitat quality (Allen *et al*., 2011). To this end, determinants of wildlife health models based on a human public health model has been proposed (Wittrock *et al*., 2019). The determinants influencing wildlife health can include factors related to: (i) biological endowment (e.g. genetics, age, reproductive status, disease); (ii) social environment (e.g. population demographics, interspecies and intraspecies competition); (iii) access to needs for daily living (e.g. quality habitat and food); (iv) abiotic environment (e.g. climate and anthropogenic pressures); (v) direct mortality (e.g. hunting and predation); and (vi) human expectations (e.g. policies and stakeholder values). Importantly, these factors were considered likely to be of practical significance to both wildlife managers and the scientists who provide data on which management decisions are based (Wittrock *et al*., 2019). By considering all the factors that contribute to health, we can assess which are most easily influenced by available tools (e.g. management actions, development of new technologies, policy changes, or outreach programmes) and thereby develop a practical framework for the promotion of healthy wildlife populations.

The concept of ecosystem health has been the topic of numerous publications, conferences, organizations and educational curricula (Rapport and Maffi, 2011). However, a recent meta-analysis of ecosystem assessments in freshwater and estuarine environments (O'Brien *et al*., 2016) indicates that less than 15% of ecosystem health studies clearly defined the term or justified their choice of health indicators. While broad criteria for ecosystem health, including stability, sustainability, vigour, vitality, organization and resilience, have been proposed, it is unclear how or how often these concepts are being applied in a practical way by scientists or natural resource managers (Costanza, 1992; Rapport *et al*., 1998; Rapport and Maffi, 2011; Lu *et al*., 2015). It has also been argued that ecosystem health is not a matter of science, but a value-driven policy construct (Cumming and Cumming, 2015). Securing consensus on what constitutes health or thresholds for acceptable ecosystem changes are context-dependent undertakings informed by local priorities, perspectives and available information. While there are accepted thresholds for many ecosystem-level harms that affect human health (e.g. water quality standards and air pollution guidelines) there remains considerable debate and uncertainty on thresholds that indicate important changes to the health of the ecosystem itself or on ecological tipping points and self-enforcing feedback loops (see van Nes *et al.*, 2016) that cause potentially irreversible changes to ecosystem function.

Establishing Metrics for System Health

For our purposes, the term 'system' is used to refer to any set of interacting biotic and abiotic components that form a unified whole. This could be at the level of an individual, a population or beyond. The metrics we propose follow a systems approach (Stoett, 2016) for examining health whereby the health of the system, as a whole, remains the focal point, while still considering the parts of the system (e.g. disease, predators, climate, food availability) and how they interact with one another.

A definition of health for any given system is a critical first step in the assessment and promotion of the system's health. From the definition, we can develop metrics that can be used to assess health, monitor dynamic processes and guide management decisions. If the goal is to shift a system to a new desired state, examining metrics over time will be important for evaluating whether our efforts to improve health are having the desired effects.

To the extent possible, metrics warrant standardization when comparing health of different systems or measuring changes within a system over time. Creating comprehensive metrics allows us to bring the scientific method to bear on the assessment and promotion of system health. Recognizing the impossibility of generating metrics that encompass every situation and system, we describe a framework for creating metrics that can be tailored to various systems (Table 3.2).

Framing the problem

After system health has been defined as clearly as possible, the first step to measuring system health is to explicitly state the goals and objectives of the health assessment and to express the expected added value as compared with single sector approaches (Zinsstag *et al.*, Chapter 2, this volume). The goals provide the justification for the resources needed to conduct an assessment and indicate how the results of the assessment will be used. Objectives describe the steps needed to achieve the goal.

To have well-articulated goals and objectives, the study system and scale of interest must be identified. The health assessment could be focused on a population, an ecological community, a metapopulation

Table 3.2. Steps in assessing system health.

Steps in assessing system health	Questions to consider
Describe the goals and objectives of the assessment	Why are we measuring the system's health? How will the information be used?
Describe the system	What are the ecological, spatial and temporal scales? What are the key jurisdictions and disciplines? What are the various stakeholder and rights holders' expectations for how the system should function or what services it should provide?
Map the system	What are the major components of the system and their relationships with other components at each ecological scale? What are the determinants of health at each scale? What human expectations must be considered at each scale?
Create metrics for mapped system processes	What are the key rates and indices? Do thresholds for acceptable rates of change need to be negotiated among stakeholders?
Highlight processes that negatively or positively impact health	Why are these deficiencies or strengths present? Can actions be taken to reduce or strengthen these processes?
Added value of a systems approach (Zinsstag *et al.*, Chapter 2, this volume)	Incremental benefit from choosing a systemic approach when compared to single sector (reductionist) approaches
Prioritize processes for management or monitoring efforts	Which system processes are best targets for management actions? Which processes can be used to monitor the system over time?

or an entire ecosystem. The complexity and associated effort of conducting the assessment, as well as the impact and degree of focus, will be directly linked to the ecological scale (Fig. 3.1). The spatial scale must also be defined. In some cases, the spatial scale will arise naturally from the ecological scale; in other cases, it may be determined by jurisdictional boundaries, available resources, or by some probabilistic sampling scheme underpinning the assessment. Next, the temporal scale of interest should be identified. The health of a system is dynamic, with the potential to change rapidly under various scenarios (e.g. introduction of novel diseases), making it important to determine the time frame over which the assessment will be applied. For example, are we interested in the change in a system's health over the last 5 years, the last 3 months, or only the present state? Are there natural fluctuations or cycles that need to be considered? If we are comparing the current state of the system to a past state or another system, the functions or attributes that we are referencing also need to be specified. Similarly, the jurisdictions that the assessment will cross should also be identified. As we expand our definition of health, it becomes likely that aspects of the system will fall within the purview of multiple agencies. Lastly, when investigating systems, it is inevitable that multiple scientific disciplines and non-academic actors like communities and authorities will need to be incorporated, as a transdisciplinary participatory process (Berger-González *et al.*, Chapter 6, this volume) into the assessment. These scientists and non-academic actors can provide requisite expertise needed to construct and implement the assessment.

As we frame our assessment, we must acknowledge that the assessment and desired state of the system are influenced by the lens of human perception (Fig. 3.2; Hanisch *et al.*, 2012). For example, we will likely define health differently for agricultural land than for wilderness. Additionally, stakeholder values and expectations play a pivotal role in determining our goals and objectives (Berger-González *et al.*, Chapter 6, this volume). For example, national

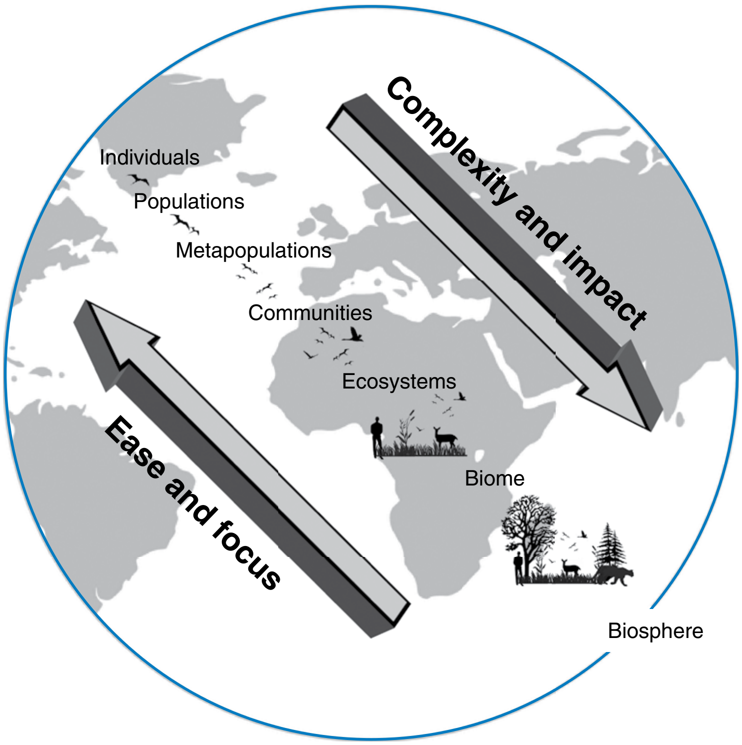

Fig. 3.1. A trade-off occurs between ease and focus versus complexity and impact when assessing system health. Although the complexity increases as the scale of the system increases, so too does the ability to have a larger impact on more system components.

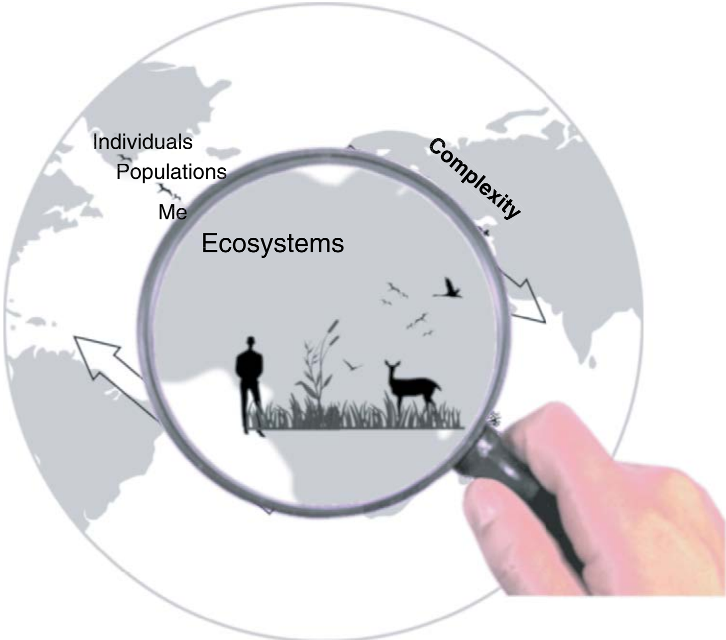

Fig. 3.2. Any assessment of natural systems is based on and affected by the lens of human perception and values.

parks or protected areas are often viewed by the public as 'pristine and wild' (Wall-Reinius, 2012). Thus, ensuring that system functioning meets the expectation of park visitors and that system attributes supporting that functioning are properly assessed is important in developing goals for the assessment and management of health within national parks. However, outside of the park, the public may have a very different view of what is acceptable. Ultimately, human beliefs, values and expectations influence every aspect of system health, and it is important that this recognition be incorporated into the health assessment as a co-production of transformational knowledge (see Box 3.1; Berger-González *et al.*, Chapter 6, this volume).

Mapping the system

Developing a system map is useful for holistically viewing a complex system in order to understand the interrelationships between the system components and their dynamic drivers as well as intervention points that can be used to change an outcome of the system. System mapping has been used on a variety of complex issues ranging from public transport use (Sedlacko *et al.*, 2014) to inequalities in healthy eating (Friel *et al.*, 2017). For all systems, defining the scale of interest is a critical first step for map development as the spatial and temporal scales will define what components, processes and interactions occur in the system and therefore warrant inclusion in the conceptual model. As the ecological scale of interest increases (Fig. 3.1), the map complexity increases.

When developing an ecological system health map, the determinants of health concept may assist in identifying the core attributes of the system upon which to focus. Wittrock *et al.* (2019) defined wildlife health as 'the ability ... to realise full function, satisfy daily needs, and adapt to or cope with changing environments'. The adoption of a determinants of health approach would dictate that the system attributes that warrant inclusion in our system map are those that permit full function (as defined by stakeholders), satisfy daily needs and allow adaptation, which are all compilations of various system processes.

One of the most effective ways to map a system is to think hierarchically starting with the simplest ecological scale and build complexity upon it. In this way, each mapped ecological scale contributes to understanding the dynamics of the entire system, and the map reflects the multiple spatial and temporal scales that comprise the system. Graphical models are useful tools for visualizing the details and complexities of a system (Fig. 3.3). These models will often start with consideration of the processes and biotic and abiotic components affecting the individual. Once the individual scale has been mapped, the population scale, or next higher ecological scale, can be mapped. The map at the population scale expands on the map depicted for the individual by now adding in symbols for key processes that link individuals within the population and drive dynamics. These could include reproduction, intraspecific competition, disease transmission and genetic diversity, and, most importantly, could include biotic and abiotic components linked to full functioning of these processes. Once the population scale is complete, the scale could be expanded to the metapopulation and include processes such as immigration, emigration, genetic mixing, disease transmission and other variables along with their biotic and abiotic components. Mapping hierarchically allows us to evaluate the critical interdependencies so that actions intended to improve the health of one component of the One Health triad (e.g. people) do not result in unconsidered impacts on another component (e.g. wildlife).

When adding features at each ecological scale to the system map, relationships among wildlife, domestic animals and humans warrant inclusion. Mapping human contributions to the system requires a great deal of consideration as intangibles such as human values as well as cultural and economic factors are widespread drivers of change in

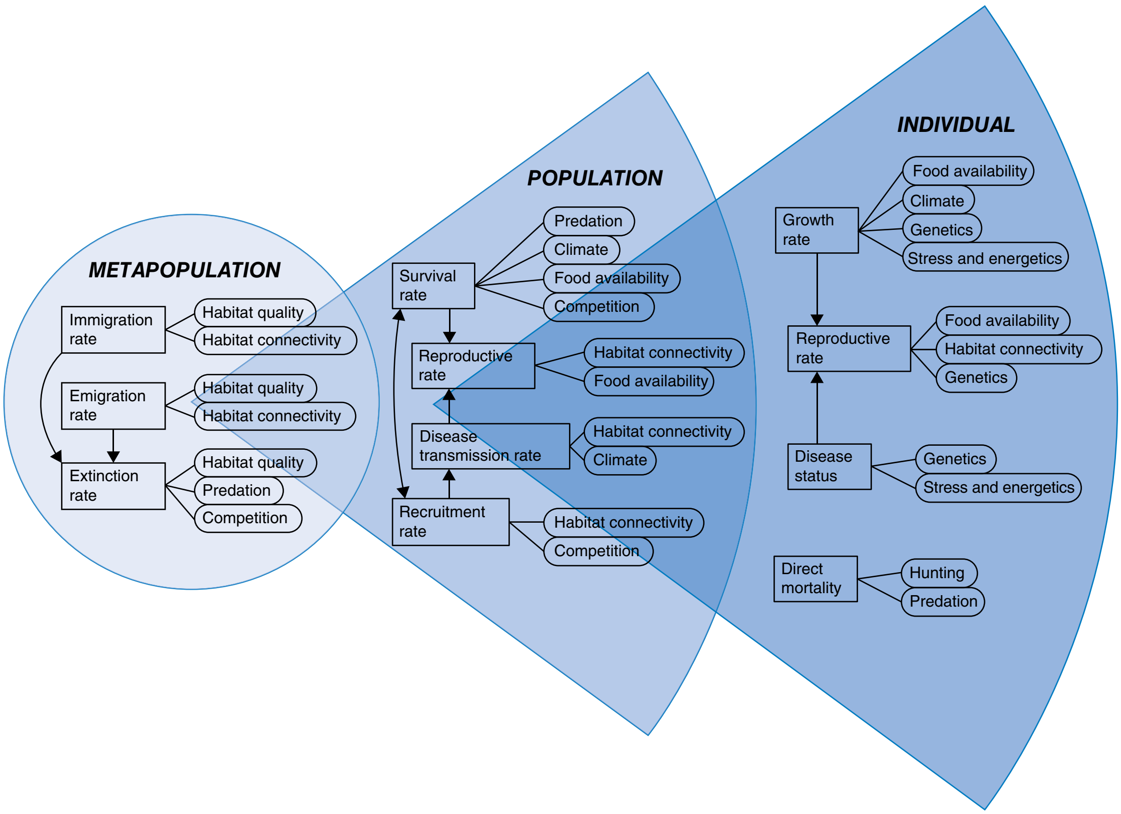

Fig. 3.3. A simplified graphical representation of components affecting a system's health. In this example, the largest hierarchical scale of concern is the metapopulation and the smallest scale is the individual. Boxes are used to represent known key processes or rates associated with health at each scale. The optimal rates at each scale are influenced by human values and expectations. Lines between boxes symbolize linkages among processes. Circles are used to represent necessary biotic and abiotic components that permit successful functioning of each process and are connected to their respective process with a line.

ecosystems (Berkes, 2004; McGinnis and Ostrom, 2014). Because humans have a direct and indirect effect on the functioning of many of the system's components, it is important that humans are mapped not only as a member of the system, but that their expectations for the system and its components are included at each ecological scale as part of a transdisciplinary participatory process (Berger-González *et al*., Chapter 6, this volume). In essence, this requires us to map the social landscape (stakeholder mapping), and wrap that landscape around our depiction of the ecological system. Inclusion of the social aspects of the system in the assessment and associated management recommendations ensures that the system is assessed within the proper context and assures that the assessment accurately captures the opportunities and limitations imposed on the system by human beliefs, values and expectations. For example, suppose our system is a population of white-tailed deer (*Odocoileus virginianus*) within a given region. Our map of the social landscape at the population scale might include the expectation that this population will provide local indigenous populations with food via hunting. Therefore, the indigenous people would be added to our map and linked to our population via hunting. Similarly, there may also be the expectation that the population is managed so that disease transmission to livestock and damage to agricultural crops are minimized. In this case, livestock producers and farmers are added to the map and linked to the population through population thresholds associated with these expectations. The social landscape also would benefit from inclusion of stakeholder groups that value the population for non-utilitarian reasons such as wildlife viewing or those that see intrinsic value of deer in the landscape. Lastly, the various jurisdictions, management agencies or organizations previously identified when we framed the problem, and who managed the mapped components or processes, will need to be linked to the appropriate system attribute on the map. The final map will depict the entire system, including important components, processes, linkages and social consideration, and as such will reflect each sector of One Health and their interactions.

Methods such as participatory system mapping (PSM), which use a facilitated process to exchange knowledge and straightforward transdisciplinary processes (Berger-González *et al*., Chapter 6, this volume) among a group of stakeholders or experts, may be useful for developing system health maps. PSM steps have been previously outlined (Sedlacko *et al*., 2014) and include defining the scope and boundaries of the system, system components, causal pathways, feedback loops, implications and knowledge gaps. The process may also be particularly relevant to development of system health maps because it allows for expression and inclusion of human values and a diversity of worldviews through development of mental models (Sedlacko *et al*., 2014). The National Cancer Institute's (2007) report on tobacco control and the UK government's obesity report (Butland *et al*., 2007) provide two detailed descriptions of systems map development and their use in directing needed interventions and policy changes for complex public health issues.

Once the system health map is developed, it will provide the structure for conducting health assessments and monitoring the effects of actions intended to improve system health. It is important to note that our understanding and, as a result, the map of the system will inevitably be imperfect and initially overly simplistic with missing components, unknown linkages and feedback loops, missing stakeholder groups, and misconceptions of system functioning. However, the system map can always be updated and improved as knowledge and understanding of the system grows.

System health metrics

Mapping the system at the scale of interest is the basis for development and selection of metrics. As each map is likely to be unique, a universal set of metrics is not possible. However, it will be important that metrics are based on the system map and correspond to the processes that are depicted. In other words, the metrics are an assessment of the system's functioning as characterized by the degree to which each critical process is operating as expected or desired.

Many of the system's processes can be measured in terms of rates (Fig. 3.3). For example, survival, immigration, emigration, reproduction, disease transmission and even stakeholder satisfaction are generally quantified in terms of their respective rates. Rates can be powerful for conducting assessments because there is often associated literature to help determine whether the measured rates are a positive or negative indicator of health. Rates can also be used as inputs into mathematical models to forecast the trajectory of the system. They allow direct comparisons between systems and can be used to measure changes over time. Similar to other studies of natural systems, the presence of epistemic and linguistic uncertainty warrants acknowledgement for system health assessments because factors such as population size are usually not precisely known and yet are needed as a denominator for many rates. Reviews of common types of uncertainty in studies of natural systems and methods to address them have previously been published (Regan *et al.*, 2002; Milner-Gulland and Shea, 2017).

When system processes are difficult to measure directly, indices may be useful for indirectly measuring the process (Johnson, 2008). Indices can be quantitative or qualitative and should be used with caution because they rely on assumptions about how they relate to the process of interest. They may also be less sensitive than direct measurements or show some lag in responding to system dynamics. Despite these drawbacks, indices can be useful tools and, in some cases, may be the only means of assessing a particular process. An example of an application using indices as metrics of system health is the United States Department of Agriculture's (USDA) tool for assessing the health of riparian systems (USDA, 2012), which uses a series of qualitative rankings associated with key processes. Questions in the tool include asking the user to rank the degree to which the riparian vegetation is composed of noxious weeds because their 'presence or occurrence ... usually indicates a downward trend in ecological condition and riparian health' (USDA, 2012). Regardless of whether the assessment tool is quantitative or qualitative, it will be important to continue to recognize that different stakeholders may have different thresholds for acceptable levels of change or system function.

Developing metrics to adequately assess how the system will respond to changes can be challenging, but it is critical that the ability of the system to adapt to change or the amount of change a system can absorb before it moves into a new state (i.e. resilience) be included in health assessments. Natural systems, regardless of ecological scale, are dynamic, and their ability to adapt to change is a key attribute of whether the system is fully functioning (Holling, 2001). Resilience of a system can be assessed by assessing its response to a perturbation (Holling, 1973). However, it is generally impractical or even unwise to experimentally perturb a system, so assessments require carefully choosing aspects of the system that provide evidence of how the system might respond to perturbations. This is where a system map becomes invaluable, because, if it has been constructed properly, it should highlight the processes that will drive change and associated system responses. For example, if we are assessing how a forest ecosystem will respond to fire disturbance, we might assess the quality of the seed bank, survey for the presence of invasive species, determine the degree to which species within the system are adapted to fire, look for evidence of past fires to understand the periodicity of fire in the system, quantify fuel loads, and so on. Using the information from various lines of evidence within the system, we can specify where in the adaptive cycle (Holling, 2001) the system currently lies and deduce how resilient the forest is likely to be to a new fire disturbance. We can also look for surrogate systems that may be similar to the system of interest but have gone through recent disturbances, and then draw conclusions from how the surrogate responded and apply them to how our system might be expected to behave or adapt under similar perturbation. Another useful set of tools for measuring resilience are mathematical models and computer simulation techniques that help forecast system responses to future change (Huyvaert *et al.*, 2018). These models could be built from our system map, with system processes connected through specified mathematical relationships, and parameterized based on the values for the various metrics we described earlier. The simulation or model is then run and resulting trajectories for the system capture not only the current state of the system but also future states if processes/metrics remain static. The adaptive ability of the system can be assessed by varying system processes based on their likely response to some change and quantifying how the new forecasts of system states have been altered compared with forecasts when processes remained static. Regardless of the chosen tool, assessing the system's adaptability cannot be ignored because it will have direct implications for system functioning and its associated health.

Once each of the system processes have been measured either qualitatively or quantitatively, processes that are not meeting stakeholder expectations or may be negatively impacting the health or function of the system will need to be highlighted. For these processes, a closer examination of why the process is not functioning to its expected potential is required. This entails examining the system map and identifying the biotic and abiotic components tied to these processes and determining where there are deficiencies. For example, if juvenile recruitment of a population is too low, resulting in forecasts of future population declines, a search for deficiencies in critical components will need to be made (e.g. a lack of thermal cover leading to nest failures). The identified deficiencies can become the target of future management actions to improve health and could drive the final recommendations arising from the health assessment.

A practical question associated with metrics and their development is where to obtain the information or data to parameterize or determine the values of the metrics. Information can be gathered in several ways. First, scientists can collect their own data by measuring the system directly. For example, data for estimating the survival rate of individuals within a population can be measured using radiotelemetry tags that alert the scientist to mortality events. Remote sensing techniques are an invaluable resource for measuring landscape level factors such as land cover, human infrastructure (e.g. roads), plant phenology and productivity, and climate and weather (Neumann *et al.*, 2015). Key parameters rates (survival, immigration, emigration, reproduction, etc.) are also available in the published literature for many systems (or from similar systems) and can be used to begin assessing metrics to assess healthy versus unhealthy states for the system. Expert knowledge and opinion can also be informative, particularly when other sources of information are lacking. Experts may include noted scientists, natural historians and agency personnel, as well as non-scientific experts such as indigenous people, who have a long and rich connection to the natural system. We can also look to novel data streams arising from technological advancements. Web-based acquisition of information based on reports from citizen scientists or the general public may prove useful, particularly for large spatial or temporal scales, and may also help describe the social landscape of the system. Similarly, documenting human use of web-based services and searches may help in understanding and quantifying human beliefs, values or expectations of a system, as well as help inform impacts to human health of system processes. Most health assessments will need to avail themselves of many different sources of information to adequately measure the various features of the system map.

Mobilizing knowledge to action

Measuring the health status of a wild population or ecosystem has its own merits but without moving this knowledge into action, little will come of it. The gaps between knowing what to do to promote health across people, animals and environments and doing it can be wide and difficult to breach. Evidence can be used to change outcomes, but only if people apply it in practice and policy.

One Health practitioners can benefit from models of individual and social change that are found in the health promotion, marketing and business literature. The Health Belief Model, for example, is one of the most widely used conceptual frameworks for guiding human health interventions. The model contains several concepts that predict why people will take a health-promoting action, including perceived susceptibility to harm, benefits and barriers to change, cues to action and self-efficacy (Champion and Skinner, 2008). The Theory of Reasoned Action and the Theory of Planned Behaviour focus on individual motivational factors as determinants of the likelihood of performing a specific action (Ajzen, 1991). They focus on how attitudes, subjective norms and perceived control influence health behaviours. Theories and models such as these can help target interventions designed to encourage the adoption of health-protecting measures on an individual or collective level.

Multiple theories of change have been developed (Mitchell, 2013) and can be used to build a bridge between what we know, what we want to achieve, and the activities it will take to get us from mapping and measuring a system's health to mobilizing what we learn into action. Given the complexity of ecosystem health, most actions will require involvement of researchers, local knowledge creators, managers, planners, beneficiaries and stakeholders at the start to develop consensus on the shared goals by explicitly documenting different views and assumptions and by helping people see how sharing their knowledge contributes to long-term positive impacts.

Knowledge mobilization is an active process of creating linkages between creators and users of information to produce value-added outcomes. The Knowledge to Action Framework was developed to help create and sustain evidence-based actions (Field *et al.*, 2014). This framework, based on commonalities of over 30 planned-action theories, follows the premise that knowledge is best co-created by researchers and those who need to use the knowledge and includes both a knowledge creation and an action cycle as transdisciplinary research (Hirsch Hadorn *et al*., 2008; Berger-González *et al*., Chapter 6, this volume). The framework provides a series of steps to help mobilize available research into action while accounting for local context and explicit assessment of barriers and facilitators to use of the knowledge for creating changes to actions. Regardless of the type of knowledge user, knowledge mobilization requires a relentless dedication to understanding that user's needs, and creating strategies and tools to engage, inform and motivate them under a variety of circumstances. A clear plan that outlines roles, responsibilities and authority to support action as well as secure the partnership and resources needed to sustain change are as essential as the efforts used to measure the health of people, animals or their shared ecosystems.

Ecosystem Health is Human Health

The connection between ecosystem health and human health is evident in the history of human morbidity and mortality, whose causes parallel land use, from mortality due primarily to predation, famine and vector-borne diseases in pre-modern societies, to the rise of infectious and waterborne diseases associated with agrarian settlements and industrial cities, and finally modern-day illnesses of sedentary lifestyles or those related to poor air quality (Rapport and Maffi, 2011). Today, increasingly rapid ecosystem degradation compounds these health effects through declines in basic ecosystem services such as provision of food and water (IPBES, 2019).

In addition to human population health, human cultural health is intimately tied to the ecosystems in which those cultures arose. Loss of biodiversity and ecosystem integrity is mirrored by loss of cultural diversity caused by similar anthropogenic pressures, including land-use change, exploitation or overharvesting of resources, environmental contamination and introduction of non-native species (Rapport and Maffi, 2011). New fields of study concerned with cultural and linguistic conservation have developed in parallel with those of ecological conservation, pointing to what has been termed a 'converging extinction crisis' of social and ecological systems across the world (Harmon, 2002).

As the One Health community has highlighted in its work with emerging zoonoses of wildlife origin, and as the risk to humans from loss of ecosystem services confirms, the health of wild populations and wild places is of importance to more than just wildlife. By conveying the importance of environmental health as a source of human determinants of health (e.g. clean water and air), actions can be promoted that contribute to conservation goals as well as human health and prosperity (Wood and DeClerk, 2015). The challenge before us is to achieve a degree of consensus among various stakeholders about what health means for a given population or system, how it can be assessed, and how it can be promoted (Berger-González *et al*., Chapter 6, this volume).

There is no single answer to the question 'What is health?' for ecosystems or their various components, be it wildlife, cattle or humans. Nevertheless, health is at the very heart of One Health, and it is an important question to ask and answer as the One Health framework continues to evolve. Without an explicit definition of the desired state that resonates across all pillars of One Health, metrics for evaluating progress towards that state, and commitment to working towards that state for all stakeholders, and addressing how an added value of cooperation between human and animal health, environment and conservation sciences can be created, there can be no true progress. The One Health community, with its multidisciplinary approach and recognition of the interdependence of multiple complex systems, is well positioned to take up this question.

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4 Grappling with Complexity: the Context for One Health and the Ecohealth Approach

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Introduction

The field of ecohealth has to do, broadly, with 'research, practice, and knowledge integration at the interface of ecology and health' (International Association for Ecology and Health, 2013). This phrase, taken from the aims and scope of the journal *EcoHealth*, is expanded in the front matter of the journal with numerous examples in the categories of 'One Health and Conservation Medicine', 'Ecosystem Approaches to Health' and 'Public Health, Ecosystems and Society'. The broad definition is similar to the conception of One Health, as a field that addresses 'interactions between human and animal health that reach far beyond individual clinical issues and include ecology, public health and broader societal dimensions' (Zinsstag *et al.*, 2011, p. 3). In practical terms, this can be framed as the 'added value [in terms of improved human and animal health outcomes, and ecosystem services] of a closer cooperation of human and animal health and other sectors' (Zinsstag *et al.*, 2012, p. 2).

We situate our discussion in this chapter within this broad definition of the *field* of ecohealth, which we are taking to encompass One Health as described in this volume. As discussed in some earlier chapters, One Health has come to be seen by many researchers and practitioners as a strategy for achieving, jointly, animal and human health outcomes that would not be possible, or if possible would be more costly and/or less effective, if undertaken by separate initiatives. The selection of outcomes, and their sustainability, are embedded in much larger and complex social-ecological systems. Grappling with the challenges of understanding this broader context is the subject matter for ecohealth.

To some applied researchers, public and animal health experts and development practitioners, 'ecohealth' has a more specific connotation. They refer to the 'ecohealth *approach*' or the 'ecosystem approach to health and well-being'. This is an approach that began to emerge in the 1990s with: (i) the expression of an ecosystem approach rooted in systems thinking, conceptualizing coupled human and natural systems, operated by collaborative processes and intended to intervene in situations of complexity and uncertainty (e.g. Allen *et al.*, 1994; Kay and Sneider, 1994; Bunch, 2001; Waltner-Toews and Kay, 2005; Waltner-Toews *et al.*, 2008); and (ii) its application to social-ecological systems for the purpose of improving human health and well-being (e.g. Yassi *et al.*, 1999; Forget and Lebel, 2001; Waltner-Toews, 2001; Murray *et al.*, 2002; De Plaen and Kilelu, 2004; Bunch *et al.*, 2006; Boischio *et al.*, 2009; Webb *et al.*, 2010; Charron, 2012; Bunch, 2016; in the 2017 special issue of *Acta Tropica* on 'Ecohealth: an African Perspective'; and Zinsstag *et al.*, Chapter 2, this volume).

The ecohealth approach is an applied and action-oriented approach intended to both improve understanding about a situation and intervene to benefit human health and well-being. To date it has mostly been applied in development contexts in the Global South, because of the origins of the approach with a development funding agency in Canada: the International Development Research Centre (IDRC).

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Dominique Charron, currently Vice President of IDRC, and, for more than a decade, the director of programmes related to ecosystems and human health, defined ecohealth as an approach that:

> formally connect[s] ideas of environmental and social determinants of health with those of ecology and systems thinking in an action-research framework applied mostly within a context of social and economic development. Ecosystem approaches to health focus on the interactions between the ecological and socio-economic dimensions of a given situation, and their influence on human health, as well as how people use or impact ecosystems, the implications for the quality of ecosystems, the provision of ecosystem services, and sustainability.
>
> (Charron, 2012, p. 6)

A wide range of researchers, practitioners and teachers have been involved in developing and applying the ecohealth approach, especially those associated with IDRC's Program Initiative in Ecosystem Approaches to Human Health, the Ecohealth Alliance, Veterinarians without Borders/Vétérinaires Sans Frontières (VWB/VSF) (https://www.vetswithoutborders.ca/ (accessed 3 June 2020)),[1] members of the International Association for Ecology and Health and Ecohealth International. Many of these organized into communities of practice in ecosystem approaches to health, in Canada, West Africa, South-east and East Asia, Latin America and the Caribbean (for example see www.copeh-canada.org (accessed 3 June 2020)). Several published training manuals for use in South-east Asia and North America (e.g. McCullagh *et al.*, 2012; Parkes *et al.*, 2017). The websites of these organizations and the journal *EcoHealth* showcase some examples of applications and development of theory and methods associated with the ecohealth approach.

In this chapter we discuss the nature of the problems that the ecohealth approach is intended to address. We present an overview of the ecosystem approach, a transdisciplinary conception of health, and principles and guidelines that bring these together in the ecosystem approach to health and well-being.

Positioning Ecohealth

For ease of communication ecohealth is sometimes described as an approach to managing environmental and social determinants of health. This is misleading because it implies a linear sequence of simple determinants and that intervention somewhere along that line will improve health. The situations to which the ecohealth approach is most appropriate are instead characterized by multiple diffuse pathways that are difficult to identify and parse, and by relationships that are self-reinforcing and resistant to change. Yet they may be subject to sudden and surprising reorganization resulting from what seem to be simple interventions.

This is because coupled human and natural systems are not merely complicated – they are complex. Complex systems do not behave like machines, with parts connected by causally linear relationships. Instead they are dominated by feedback loops that lead to self-organization and evolutionary behaviour, they have interacting, multi-scalar hierarchical settings, they adapt and evolve, and they are characterized by irreducible uncertainty.[2]

Such situations tend to defeat our normal approach to problem solving. Since the scientific revolution of the 17th century, we have been trained to deal with problems that can be compartmentalized, isolated and reduced to manageable cause–effect relationships. Furthermore, our institutions (health authorities, planning departments, etc.) are structured and operate in this old paradigm (Bavington, 2002; Berkes, 2003; Innes and Booher, 2010). Because the application of 'normal science' (described by Kuhn, 1962) and applied and professional consultancy work rooted in that paradigm is sometimes inadequate, some researchers and practitioners have attempted to find other pragmatic ways to deal with complex problematic situations. In particular, Funtowicz and Ravetz describe a 'post-normal' approach (Funtowicz and Ravetz, 1993, 1994a,b, 2003, 2018) that is relevant to ecohealth (see Table 4.1).

Post-normal science (PNS) is a way of doing policy-related science that is appropriate for cases where 'facts are uncertain, values in dispute, stakes high and decisions urgent' (Funtowicz and Ravetz, 1994b). PNS provides a basis for accommodating knowledge provided from multiple perspectives of diverse stakeholders in complex situations. PNS thus offers a philosophical rational for health-related activities where One Health is invoked as a goal and/or ecohealth is chosen as an approach.

For One Health practitioners, this means that the health outcomes selected, and the manner in which they are addressed, become part of the process of investigation. For example, livestock are valued in many different ways, many of them non-economic (Zinsstag *et al.*, Chapter 2, this volume). Cattle, for instance, are valued differently by Maasai in East Africa, Hindus from India, and feedlot owners

Table 4.1. A comparison of the normal applied, professional consultancy and post-normal science (PNS) approaches to environmental problem concerns. From Kay *et al*. (1999), reprinted with permission.

Normal applied science	Conventional professional consultancy	PNS and inquiry
Essentials		
Certainty	Uncertainty (reducible in principle, we lack knowledge)	Uncertainty (irreducible in principle)
Low stakes	Intermediate stakes	High stakes
Facts: truth found	Solution: client happy, society is satisfied	Resolution: a course of action is chosen
Results		
Hard	Try to be hard	Soft
Predictable	Error reduced to an acceptable level	Unpredictability a fact of life
Quantitative	Quantitative	Quantitative + Qualitative
In the service of		
Truth	Client in a societal institutional framework	Decision makers, policy, public
Judgement of results		
Truth accepted	No mistakes (i.e. surprises)	Quality of process, integrity
Peer review	Holds up in court, client happy	Holds up to public scrutiny, move forward
Mode of inquiry		
Hypothesis testing	Problem solving	Ecosystem approach
Pursuit of truth	Mission and product oriented	Pursuit of understanding
Reductionism	–	Holarchic
Analysis	Analysis + Design	Analysis + Design + Synthesis
Explanations		
Linear cause and effect	Non-linear, negative feedback	Negative + Positive feedback, autocatalysis, morphogenic causal loops
Mechanistic	Mechanistic + Cybernetic	Synergistic, emergence
Stability	Control, homeostasis	Change, evolution, ∞ cycles
Efficiency	–	Efficiency + Adaptation
Extremum principles	–	Local optimum, trade-offs
Laws	–	Propensities and constraints
Forensics		
Fact	Interpretation	Testimony
Characteristics		
Objective, one correct view	Subjective, client-consultant view	Subjective, plural
Value free	Limited values	Ethical, integrity
Predictive management	Control management	Anticipatory + Adaptive management
Physics	Engineering	Ecological economics

exporting beef from the USA. Simple appeals to cost–benefit analyses to arrive at strategies for controlling diseases are not always helpful or sufficient. Even within a broad economic perspective, we must ask whether the benefits and costs accrue differently to smallholders, corporations, communities, trading partners and the like. PNS, unlike what has been called normal science, does not argue that there is a single 'objective' view of a complex reality that transcends all the others. Conventional scientists contribute a great deal to the overall body of knowledge, but their view does not necessarily negate or subject others. Our understanding of the world emerges from multiple, sometimes conflicting, perspectives, and is characterized by complex uncertainties.

In order to prevent this openness to multiple perspectives from degenerating into a free-for-all mixture of hard-won evidence, misinformation and fantasy, PNS practitioners have developed extended peer networks and sets of guiding principles and questions. Hence the importance of networks and communities of practice that cross not only disciplinary boundaries but also boundaries that have traditionally separated academic scholarship from community-based research and indigenous knowledge (Berger-González *et al.*, Chapter 6, this volume).

The Ecosystem Approach

Ecosystem approaches are distinguished from other approaches in environmental and resources management by the use of the ecosystem construct as a metaphor for holistic thinking, attention to the evolutionary and dynamic nature of complex situations, and the incorporation of processes to accommodate management of such situations with multiple interests and stakeholders, and across multiple jurisdictions (Yaffee, 1999). Figure 4.1 presents a version of the 'diamond diagram' that represents the adaptive ecosystem approach that has influenced many ecohealth applications. This version of the ecosystem approach (Bunch, 2001) was based on that developed by James Kay and his colleagues in the 1990s (Kay *et al.*, 1999) and further elaborated in the book *The Ecosystem Approach: Complexity, Uncertainty and Managing for Sustainability* (Waltner-Toews *et al.*, 2008). This expression of the ecosystem approach is explicitly positioned as PNS and informed by ideas about self-organizing, holarchic and open (SOHO) systems. While challenging to understand for the novice, the language and theory of these systems has provided a useful way to think about, and manage, what might otherwise appear to be a kind of paralysing complexity and to anticipate and plan for unintended consequences.

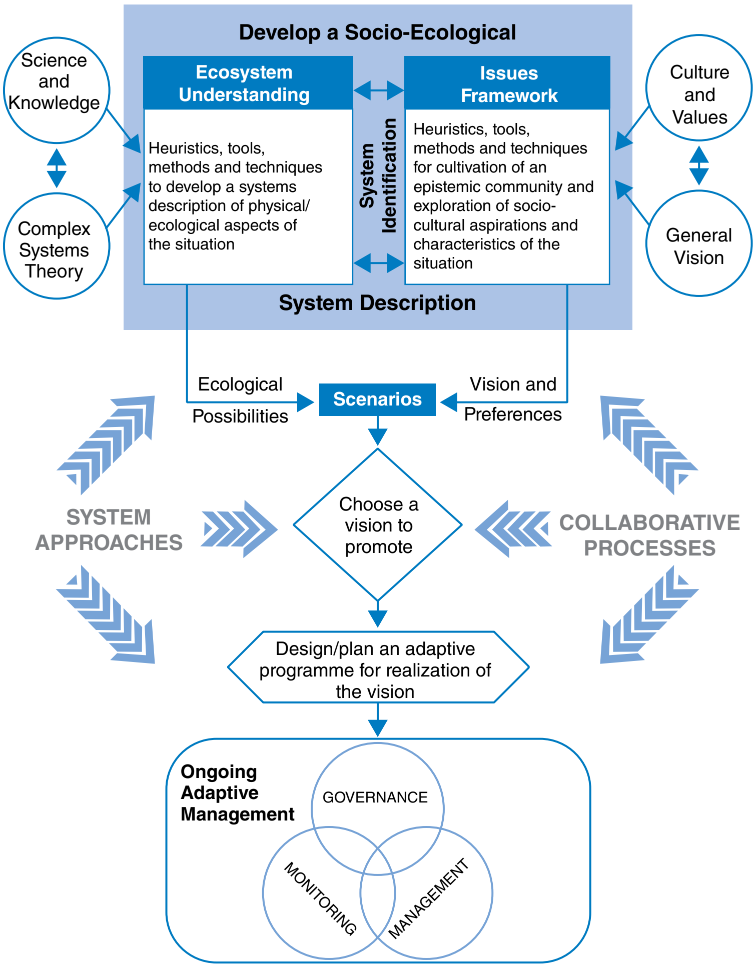

Fig. 4.1. A framework for an adaptive ecosystem approach. From Bunch (2001), adapted from Kay *et al.*, 1999.

Self-organization is a characteristic of complex systems that leads to emergence, and is related to systems and complexity science concepts such as resilience, adaptation, regime change and tipping points. Within the One Health field, one might think of the health of individual animals and people being embedded in, and interacting with, families or herds, which are nested within larger social and ecological units, which are further nested within – affecting and being affected by – global trading and climate systems. People and individual animals have their own particular characteristics (emergent properties), as do families and herds and so on. Each unit (person/animal, herd/family) can be viewed as both a whole, with its own internal dynamics, and also as a part of something larger. Philosopher Arthur Koestler (1968) referred to such 'two-faced' units as holons, and the nested organization as a holarchy.

This way of looking at the world implies the need to identify appropriate scales of attention as well as within- and across-scale interactions – which for many human health and animal health workers is a formalization of common sense. Does one target individuals, households, communities (or their animal counterparts), or some combination? The 'open systems' of the SOHO concept refers to the fact that such systems are those in which information, energy or matter (inputs) flow through, are transformed in, and drive the processes occurring within systems. The SOHO concepts are some of the systems thinking ideas used by practitioners throughout the application of the ecosystem approach.

There are three general phases evident in the ecosystem approach framework presented in Fig. 4.1: (i) problem identification and system description (the box at the top of the diagram); (ii) making decisions and taking action; and (iii) ongoing learning, adaptation and management that subsumes and iterates the process. In this general framework methods and techniques are not prescribed, although both systems approaches and collaborative process are intended to operate the approach throughout.

Problem identification and system description (sometimes called a system study) begin the engagement with a messy problematic situation, including stakeholders and actors. An important part of this is the identification and description of the 'problemshed'. (This may be tied to geographic constructs such as watersheds.) It involves developing an appreciation of the nature and spatial and temporal scales of relationships associated with a problematic situation. It is a collaborative process of discovery to understand historical context, identify and meaningfully engage and empower actors and stakeholders, develop knowledge about key components and relationships, understand pertinent values and preferences and physical and cultural possibilities. This work draws key relationships in the system to the fore, indicating their spatial and temporal footprint and bounding the situation so as to identify the system, its wider systems and environments and subsystems and components.

The social-ecological system identification generates understanding of systemic possibilities that might exist in the situation. From this, researchers work with stakeholders to identify alternative futures (scenarios) that are systemically desirable and culturally feasible. One of these alternatives is selected to inform intervention. This is a different role for researchers than that with which traditional scientists will be familiar, and it is a characteristic of working in the 'post-normal' mode in situations of uncertainty and complexity. James Kay (2008), a key formulator of this type of approach, explains that:

> Investigators into complexity do not seek prediction, control, right answers or efficiency. These are not sensible goals under conditions of complexity. Rather, the investigators seek understanding, adaptability, and resilience. Scientific inquiry, more than ever, becomes an act of collaborative learning and knowledge integration. The role of the expert shifts from problem solving to an exploration of possibilities and from giving correct advice to sharing information about options and trade-offs. In fact, those who cling to being the old sort of expert lose their expertise.
>
> (Kay, 2008, p. 80)

This new role for experts derives from the failure to manage complex situations using reductionist and mechanistic ways. Such situations are characterized by discontinuities in linear chains of cause and effect. They cannot be managed as if they were sets of levers and cogs in a machine. Instead, complex systems must be encouraged to self-organize around desirable alternative system configurations. A system's trajectory of change cannot be entirely controlled, and there may be surprises along the way. It is more analogous to raising a baby to adulthood than to sending a spacecraft to the moon. With the rocket, there is a relatively high degree of certainty of the outcome, each successive attempt is similar in critical ways and sending one successful rocket improves the chances of the next. In raising a child, experience and expertise help, but the outcome remains uncertain. Each child is unique and formulae have limited application (Glouberman and Zimmerman, 2002).

Thus, when we attempt to understand and intervene in complex situations, we need to monitor key relationships to learn about system behaviour. This is necessary to be adaptive. Applied research, public health interventions, and other projects that attempt to engage with complex environment-and-health problems must constantly re-evaluate the conceptual model of the system and the efficacy and outcomes of interventions. There should be openness, even an orientation to revising and adjusting the strategy. The ecosystem approach is an adaptive management approach. Practitioners of adaptive management monitor in order to support collaborative learning.

Based on the 'diamond diagram' in Fig. 4.1, AMESH (Adaptive Methodology for Ecosystem Sustainability and Health) was developed in the 1990s through a series of community-based projects in Kenya, Peru, Nepal, Canada and several other countries (see Fig. 4.2). AMESH is described in considerably more detail elsewhere (see Waltner-Toews *et al.*, 2008). However, as applied to One Health outcomes, it may be summarized as follows:

- The process begins when local people, researchers or some third-party agency perceive a health-related problem.
- The responders, who could be anyone from international agencies to university-based research scholars, describe the situation systemically, including as many different perspectives and scales as feasible.
- Local stakeholders, together with research scholars and government and non-government agencies identify alternative courses of action that can best accommodate known trade-offs and optimize the achievement of multiple goals.
- They then choose a course of action that can achieve some balance of those different goals, develop a plan that incorporates feedback from which the implementers can learn and adapt, begin implementation, and ensure that governing, monitoring and management co-evolve with the changing situation.

The process, which has been demonstrated to be quite robust, incorporates both conventional investigative scientific and modelling techniques and democratic social processes, and, unlike many scientific investigations, can be altered and adapted to deal with new information and/or changing contexts (e.g. unstable markets for animal products, disease epidemics and the like).

An Integrated and Transdisciplinary Conception of Health

Because ecohealth applications face the danger of exploding in multiple directions at once, practitioners and scholars in the field have developed a variety of ways to set reasonable boundaries and articulate key principles.

Health (good or bad) arises from multiple interrelationships among various human and natural components of social-ecological systems (Whittaker *et al.*, Chapter 7, this volume). In systems terms, community, population or ecosystem health is an emergent property. That is, it is evident at the level of the system but not at the scale of individual components or smaller subsets of relationships. One cannot predict from the individuals what the community will be like. Thus, one way to bound ecohealth work is to find units that are simultaneously useful for study, for administration of programmes, and for investigation of dynamics. This is part of defining the 'problemshed' relevant to the situation. Some geographic constructs lend themselves to this application more than others. In environment-and-health situations, watersheds have proven to be such a unit (Davies and Mazumder, 2003; Venema and Bunch, 2011; Bunch *et al.*, 2014; Morrison *et al.*, 2017). Not only are they arranged in a hierarchical manner (with sets of larger encompassing catchments and smaller subwatersheds) that help to frame conversations about external driving forces and upstream/downstream relationships, but water is clearly of central importance to both ecological and human health (Falkenmark and Folke, 2002; Boelee *et al.*, 2019; WHO, 2019).

There are several useful conceptual models of environment-and-health interrelationships and emergence, such as the butterfly model of health (VanLeeuwen *et al.*, 1999), and the Millennium Ecosystem Assessment framework that connects ecosystem services to constituents of human well-being (Corvalan *et al.*, 2005). One current model that we find particularly useful is the Watershed Governance Prism (Fig. 4.3; Parkes *et al.*, 2008,

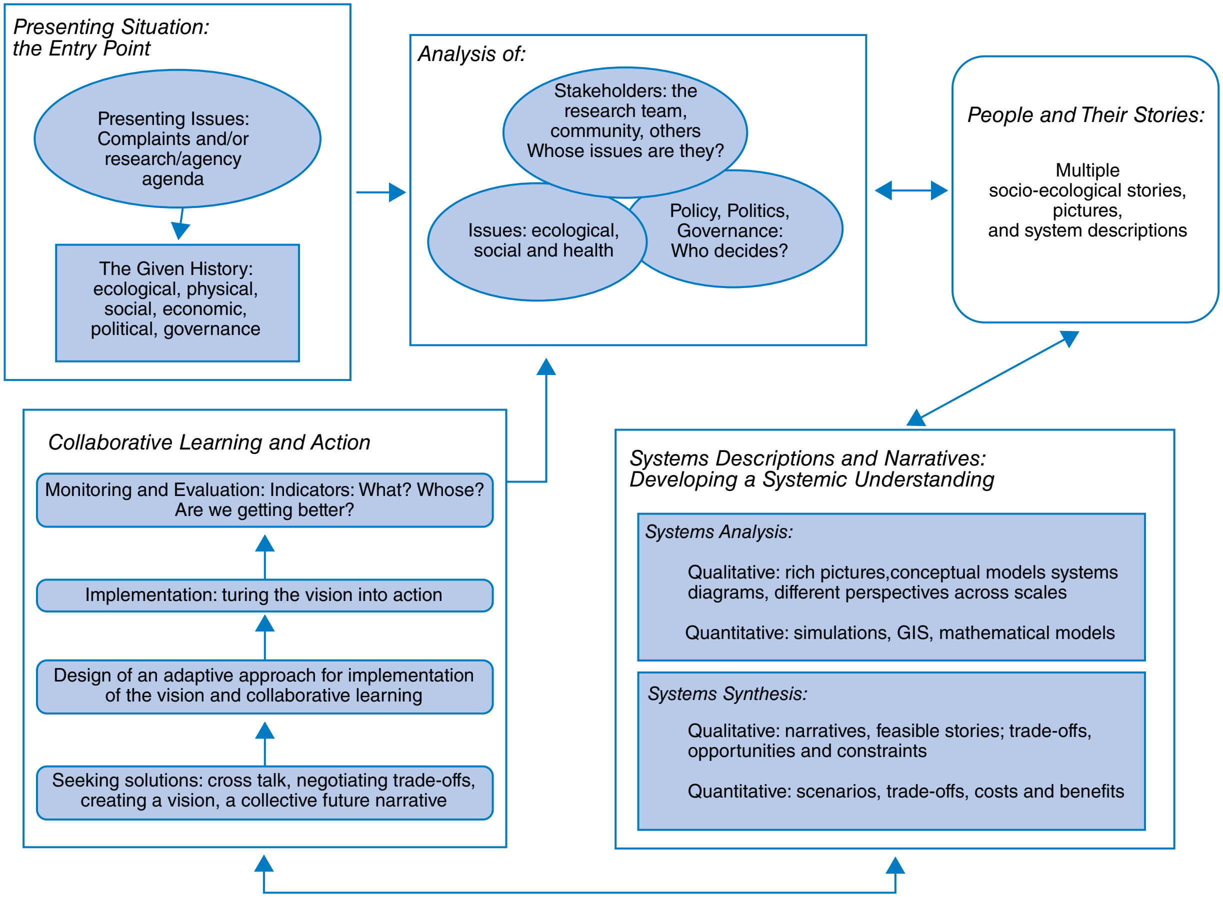

Fig. 4.2. The Adaptive Methodology for Ecosystem Sustainability and Health (AMESH). GIS, geographic information system. From Waltner-Toews *et al*. (2004), reprinted with permission.

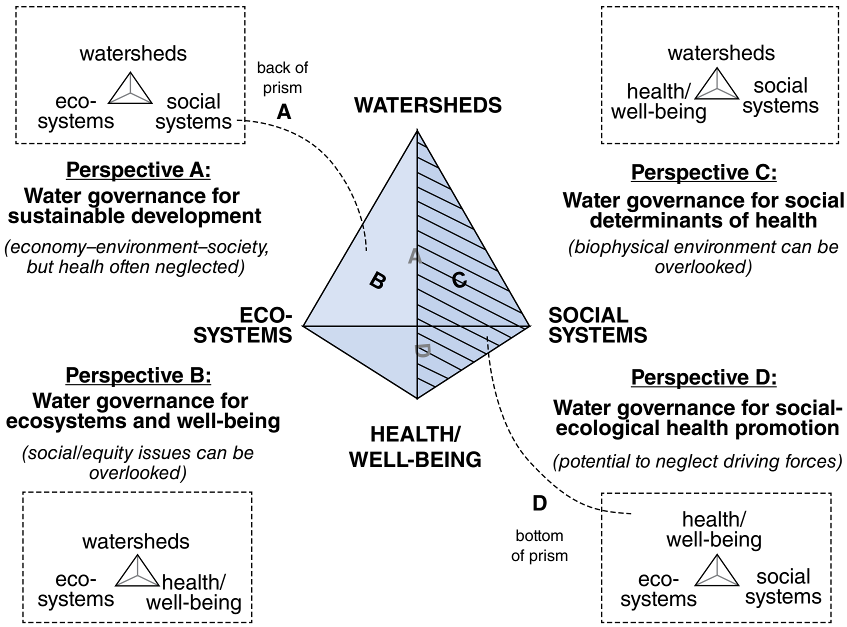

Fig. 4.3. The Watershed Governance Prism. From Parkes *et al*. (2008), reprinted with permission.

2010). The prism expresses the potential for relationships among social systems, ecosystems and health with watersheds as an organizing construct that highlights water–land interaction, settings for health and well-being, and scale at which important driving forces (such as climate change) manifest. Although the prism is labelled for 'watershed' governance, because watersheds represent a setting to understand social-ecological systems and driving forces acting up on them, this can be substituted for other settings.

The Watershed Governance Prism is useful as a heuristic device to conceive of and guide the search for important relationships in a complex and problematic situation (e.g. among social systems and health, watersheds and social systems; see Table 4.2). Not every axis of the prism will necessarily be identified as important in every situation, but in identifying the problemshed and developing a system description of the issue, the prism can inform our scan of the problem. Furthermore, sets of relationships can be built up to represent common perspectives (e.g. the faces of the prism correspond to common approaches such as: (i) water governance for sustainable development; (ii) water governance for ecosystems and well-being; (iii) water governance for social determinants of health; and (iv) water governance for social-ecological health promotion). The Watershed Governance Prism thus helps to promote the search for relationships corresponding to various prism axes that may exist in a problem context, and also point out what aspects may be missing or neglected. When a conceptual model of a problematic environment-and-health situation is developed, some axes might not appear, but this can be a deliberate and justified choice, avoiding an accidental omission that arises out of ignorance or a narrow perspective.

The Watershed Governance Prism and other conceptual models of environment and health promote a holistic and synthetic approach to complement the normal scientific and social science tools that we can bring to bear on environment-and-health issues. This highlights the necessity for inter- and trans-disciplinarity in addressing such problems. The term 'governance' also points to the need for collaborative and participatory approaches in the understanding and management of health and well-being as emergent properties of complex and coupled human and natural systems.

Another way (apart from defining organizational or geographic units) to manage the challenging process of doing ecohealth work has been to define basic principles. Dominique Charron from Canada's IDRC articulated six key principles or guiding considerations (Charron, 2012). These principles echo

Table 4.2. Relationships corresponding to axes on the Watershed Governance Prism. Adapted from Parkes *et al*. (2010).

Linear connections (prism 'axes')	Representative examples of features, issues and characteristics of linear connections' link to prism diagram
Ecosystems–health/well-being	Traditional environmental health relationships linking ecosystems with human health and well-being, with a focus on contaminants, pathogens, disease vectors, toxic or therapeutic agents, extending to health implications of loss of biodiversity and/or ecosystem services.
Watersheds–ecosystems	Natural resource and ecosystem management (including land and water use) within the watershed, agroecosystem viability and food security; the protection of baseline or 'environmental' water flows, including wetlands; saltwater intrusion/salinization of soil.
Watersheds–health/well-being	Water-related services and infrastructure (including source water protection, wastewater, sanitation and hygiene services); direct effects of natural disasters such as flooding, drought, landslides; structural flood defences, drainage and irrigation systems.
Watersheds–social systems	Water for socio-economic and community development; water access and water rights (particularly for the poor); public or private exploitation of water for economic gains through dams, reservoirs and hydroelectric power; upstream-downstream equity issues; spatio-temporal variability.
Social systems–health/well-being	Social determinants of health; health implications of social policies and socio-political processes, health impacts of socio-economic status, inequities, poverty, social networks and social cohesion; access to health services, health promotion, education, social services and community development.
Ecosystems–social systems	Linked social–ecological systems; ecological goods and services (i.e. provisioning, supporting, regulating and cultural services); supply and demand-side management, place-based links of human-natural systems occurring at scales within and beyond watersheds.

the ecohealth approach and conception of health presented above. They include:

- systems thinking;
- transdisciplinary research (i.e. research that engages community members and not just scholars) (Berger-González *et al*., Chapter 6, this volume);
- participation (which is an extension and elaboration of trandisciplinarity);
- ecological sustainability;
- gender and social equity; and
- knowledge-to-action.

Of course, each problematic environment-and-health situation in which we might intervene is unique. Thus, different applications of the ecohealth approach emphasize these principles to different extents and use a wide variety of ways to mobilize these principles. For example, over 5 years, the Dahdaleh Institute for Global Health Research at York University will draw upon complex adaptive systems theory and employ agent-based modelling, developing scenarios to understand climate change impacts and human health in the Chilwa Basin of Malawi. Partnered with Dignitas International and local communities, they are building capacity to understand interactions of extreme weather, ecological services, infectious diseases, food security, clinical public health and disaster risk management to target deficits in ecological services management and clinical and population health interventions (J. Orbinski, 2019, unpublished data). While connecting with all six principles of the ecohealth approach, the systems thinking principle is formally and strongly emphasized in this project.

Waleckx *et al*. (2015) on the other hand, in their approach to managing Chagas disease in the Yucatan, dealt with systems less formally, mobilizing community knowledge to identify interrelated behaviours, knowledge, attitudes and perceptions of community members, along with environmental factors to inform interventions. They operated an iterative process with local government, social workers, community members, carpenters, the health centre and the research team, in which they explored and agreed upon strategies for intervention. Each stakeholder played a different role in the process, which involved interventions such as installation of window screens and education about cleaning of chicken coops. This project strongly emphasized the transdisciplinary and participation principles.

Another example involving 'complex adaptive systems' is offered by an ecohealth project in Chennai, India (Bunch *et al.*, 2005, 2006, 2019; Kumaran *et al.*, 2012). In this project researchers partnered with community members in low-income squatter settlements ('slums'). Participating communities were formally conceived as 'social-ecological systems' that were characterized by recurring outbreaks of cholera and other disease, inadequate solid waste disposal, poor or absent toilet and sewerage facilities, poverty, malnutrition, low levels of literacy, poor access to potable water, and child labour. They faced continued pressures of the caste system, urbanization, political conflict and lack of tenure; they were stuck in a resilient (maladaptive) poverty trap. The partnership worked to build community capacity to manage this situation and improve human well-being. This project looked less to the natural environment and ecological sustainability than did the previous examples, but emphasized gender and social equity more strongly, along with participation and systems thinking.

In these projects and others, given the strong resistance of certain populations to global health and animal health interventions, the involvement of stakeholders and sharing of knowledge as it emerges have been demonstrated repeatedly to be essential not just to generate knowledge (i.e. from a PNS perspective), but also to implement effective programmes.

Future Directions for Ecohealth

Ecohealth and One Health as currently defined are relatively new fields, and the feedback loops between practice and theory are still influencing each other, resulting in both richer theory and more effective practice. Some recent explicitly 'ecohealth' research initiatives include projects working with communities to understand and facilitate responses to climate change in equatorial Africa, Canada's far north and the Peruvian Amazon, connecting conservation and human well-being in Costa Rica, studies on mercury dynamics in the Brazilian Amazon, social-ecological impacts of Agent Orange in Vietnam, and development of interactive, open-source teaching materials in Canada, Africa, Asia and Latin America.

In the realm of One Health, initiatives assume particular goals such as eradication or management of zoonotic and other animal-related diseases. In these cases, clear goals can be set, programmes undertaken, results achieved with some predictability, and the value-added benefit of joint human-animal strategies calculated. In the long run, however, One Health activities will need to be understood in a context of global social-ecological changes, where outcomes are less certain (Zinsstag *et al.*, 2011).

A current example of what can occur when normal, linear science is applied to managing complex systems emerged in late 2019 and early 2020. In 2019, more than 200 million pigs in China died from – or were killed to 'stamp out' – African swine fever (ASV). That was about half of the pigs in China and a quarter of all the pigs in the world. In late 2019 and early 2020, hundreds of millions of Chinese people were in markets and malls searching for scarce meat to celebrate the end of the lunar 'Year of the Pig' and launch the 'Year of the Rat'.

While pigs were in short supply, the Huanan Seafood Market in Wuhan, Hubei Province, China, was well stocked with other species to help their customers stock up for the celebrations. These included peacocks, wild rabbits, snakes, deer, crocodiles, turkeys, swans, kangaroos, squirrels, snails, foxes, pheasants, civets, ostriches, camels, cicadas, frogs, roosters, doves, centipedes, hedgehogs and goats.

In January, 2020, the *South China Morning Post* reported an outbreak of H5N1 avian influenza in Hunan Province, which is geographically adjacent to Hubei Province. Since 2003, tens of millions of birds have died from avian influenza, and hundreds of millions have been slaughtered. The World Health Organization (WHO) has reported that, since 2003, avian influenza has infected less than 1000 people worldwide, killing about half of them.

It should not come as a shock that within weeks, economic anxiety, rather than pandemic death, rose to the top of the headlines. In each area – agriculture, disease control, economic policy – application of good normal science had resulted in improved yields, low disease rates and increased profits.

Responses to these epidemic diseases were targeted on surveillance, containment, vaccine development and the like. These responses are all appropriate as emergency measures based on the best practices of normal science. But what of long-term agriculture, health and economic policies?

For those thinking in terms of PNS, the concurrent emergence of COVID-19, ASV, avian influenza and global economic uncertainty is no surprise. But few have addressed the underlying social-ecological conditions which would be useful for developing linked economic, public health and agricultural policies. Similarly, few have researched those questions in relation to suggestions that entomophagy or veganism could be one-size-fits-all solutions to climate crises, hunger and sustainable development (Waltner-Toews, 2017).

What are the larger implications of choosing certain health-related outcomes such as disease control or food production over others such as local community autonomy and resilience, and equitable and sustainable distribution of both production and consumption? Do shifts towards eating insects, less meat or more almonds result in more resilient social-ecological systems? It is in the context of these larger questions that ecohealth and its theoretical (complexity) and philosophical (PNS) bases are most relevant, and where One Health will ultimately demonstrate its worth.

Notes

[1] The *Ecohealth Training Manual* developed by the Southeast Asia Ecohealth Field Building Initiative contains practical elaborations of many of the ideas in this chapter (available at: https://www.vetswithoutborders.ca/library/fbli (accessed 3 June 2020)).

[2] This characterization of a complex situation is founded on a tradition of systems thinking and complexity science. It also corresponds well to Alfred North Whitehead's 'process philosophy' – see for example Whitehead (1978) and Barbour (1997).

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5 Towards a Healthy Concept of Health

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One Health as an Interdisciplinary Multispecies Health Approach

Two distinct ways of using One Health

The term 'One Health' is used in two distinct ways. First, it has been used as denominating a specific approach with origins in the 19th century combining veterinary and human medicine (Lerner, 2013). Through time this approach has widened substantially (Bresalier *et al*., Chapter 1, this volume). In a second way, the term is nowadays used as an umbrella for many approaches with a strong multispecies and multi- or interdisciplinary scope such as One Health, ecohealth (Rapport *et al*., 1999), health in social-ecological systems (Zinsstag *et al*., 2011), planetary health (Whitmee *et al*., 2015) and others. In order to avoid confusion and the risk of losing particular features of the specific One Health approach, one needs to separate between these two usages. One simple solution is to strictly use 'One Health approaches' when referring to the second sense and 'One Health' or 'the One Health approach' when referring to the first sense.

This chapter will focus on the One Health approach, its definition as well as implications of the definition. In order to aim for a 'healthy' concept one always needs to analyse how the concept is defined and where the boundaries to other concepts are. In everyday work, many crucial concepts such as health are not explicitly defined, rather one uses an implicit working definition. However, in dilemmas when one needs to think whether a certain state belongs to health or not, one needs to start thinking of the explicit definition of the concept of health. Here, our concept analysis will focus on different definitions of the One Health approach, what 'One' implies in terms of trans- and interdisciplinarity, and how to define 'Health' within the One Health approach.

Definitions of the One Health approach

There are several ways to define the One Health approach. The choice of definition influences where the boundaries for the approach are. One could distinguish a narrow and a wide approach of One Health (Lerner and Berg, 2017). In the narrow approach, One Health research is mainly constituted by collaborations between veterinary medicine and human medicine. In the wide approach, biological sciences, health economy and social sciences are also contributing to the research. Nowadays, the narrow approach is more or less abandoned in favour of the wide approach.

There are several wide definitions of One Health. In this book, Zinsstag *et al.* (Chapter 2, this volume) propose the following definition:

> One Health [can thus be defined] as any added value in terms of health of humans and animals, financial savings, social resilience or environmental sustainability achievable by the cooperation of human and veterinary medicine and other disciplines when compared to the two medicines and other disciplines working separately.
> (Zinsstag *et al*., Chapter 2, this volume, p. 16)

This approach is narrow in the emphasis on human and veterinary medicine. However, it is also wide in considering economical and biological sciences. Crucial for this definition is that there needs to be inter- or transdisciplinarity in order to achieve a One Health approach, because one cannot talk

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about One Health if there is no added value from transdisciplinarity.

Let us now compare this definition with some other definitions of the One Health approach. Gibbs (2014, 2018) has earlier gathered and compared different descriptions of One Health, but these three discussed below are present at the moment on their organizations' homepages.

The One Health Initiative defines One Health as:

> Recognizing that human health (including mental health via the human-animal bond phenomenon), animal health, and ecosystem health are inextricably linked, One Health seeks to promote, improve, and defend the health and well-being of all species by enhancing cooperation and collaboration between physicians, veterinarians, other scientific health and environmental professionals and by promoting strengths in leadership and management to achieve these goals.
>
> (One Health Initiative, 2008)

The One Health Initiative definition focuses on interdisciplinarity. This is similar in one aspect to the definition used in this book, but the added value by transdisciplinarity is not recognized. The One Health Initiative definition is wide in recognizing all aspects of health care for humans, animals and the environment.

The World Health Organization (WHO) defines One Health as: 'an approach to designing and implementing programmes, policies, legislation and research in which multiple sectors communicate and work together to achieve better public health outcomes' (WHO, 2017). This definition focuses on the collaborative multidisciplinarity. Here, a more narrow view on health occurs due to focusing on better public health outcomes.

The One Health Commission defines One Health as: 'a collaborative, multisectoral, and transdisciplinary approach – working at local, regional, national, and global levels – to achieve optimal health and well-being outcomes recognizing the interconnections between people, animals, plants and their shared environment' (One Health Commission, 2009). The One Health Commission definition focuses, as does the definition in this book, on transdisciplinarity. There is an emphasis on health that is a connection between human, animal and plants in their environment.

To summarize, when one looks at collaboration, the definition in this book and that of the One Health Commission demand a transdisciplinary approach giving added value to, for example, research. The other two definitions are focused on multi- or interdisciplinary work. If one instead looks at which organisms are covered, the definition in this book is narrower than the One Health Commission (which explicitly also includes plant health) and the One Health Initiative (which includes ecosystem health) definitions. However, it is wider than the definition elaborated on the WHO homepage (referring to public health).

The Demarcation of 'One' in One Health

'One' in One Health refers to several sciences working together towards the same goal. To work together could imply different things, and the One Health approach in this book is not aiming for multidisciplinary science, which is when several disciplines work in parallel with each other while studying a subject. Rather it aims for trans- and interdisciplinarity (Berger-González *et al.*, Chapter 6, this volume). To be able to call something a One Health research study, there needs to be trans- and interdisciplinarity involved, otherwise the research is public health, human medicine, veterinary medicine, health economics or social science. Also, a transdisciplinary approach aims for including more than science, thus, collaboration between researchers, policy makers (e.g. politicians, non-governmental organizations (NGOs)) and practitioners is needed in One Health.

The added value from inter- and transdisciplinary science has also been addressed in other studies. Manlove *et al.* (2016) found in a literature survey that many of the One Health publications could be clustered in three different silos and although more overlap between the silos occurred through time, this was still the case. In order to benefit inter- and transdisciplinary science, crucial for One Health, Rüegg *et al.* (2018) created a One Health index (OHI) to evaluate whether research is One Health or only focused on one discipline. The authors suggest that it might be less beneficial if the OHI is too high or too low, but the optimal range of the OHI index is still unclear. That could be used either to visualize how to make research more inter- or transdisciplinary, to show how the index changes over time, or as a tool to use in the distribution of funding.

Fig. 5.1 attempts to illustrate a Boolean depiction of the different terms and concepts relevant to different One Health approaches. One Health is at the intersection of human (public) health and

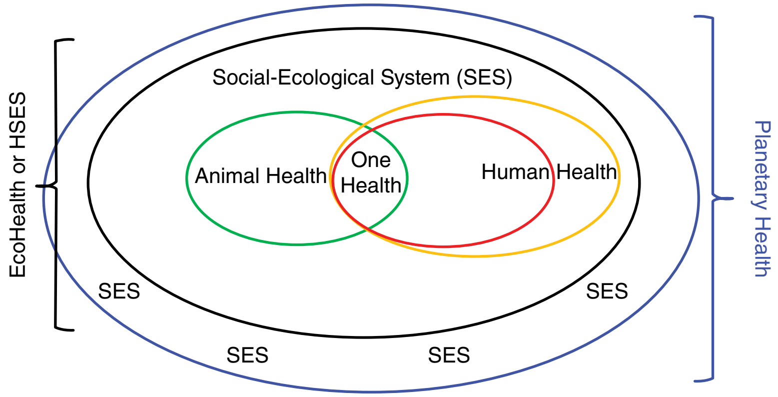

Fig. 5.1. Boolean depiction of health concepts and approaches to health. All these terms and concepts are relevant to One Health approaches. Green, animal health; red, human (public) health; yellow, global health; black, ecosystem approaches to health (ecohealth) or health in social-ecological systems (HSES); blue, planetary health.

animal health. Global health extends public health to an international level but does not include animal health. Ecosystem approaches to health (ecohealth) have a stronger emphasis on ecology and more sciences from the arts and humanities are included and thus clearly encompass One Health (Lerner and Berg, 2017). Planetary health is more anthropocentric and attempts to relate health with global change phenomena such as climate change (Lerner and Berg, 2017). This has also been found in a scientometric analysis of scientific papers within the field of planetary health (Falceto de Barros *et al.*, 2019).

The Demarcation of 'Health' in One Health

The concept of health is crucial to define for the One Health approach. To promote health, one needs to have a clear idea of what kind of health one aims for. Policy work as well as how to allocate resources are dependent on what is included in health. However, there is a lack of theoretical discussion on how to define the concept within the One Health approaches. Health is much more complicated in One Health approaches than, for example, in global health, where only human health is considered. In One Health approaches, at the least both human and animal health need to be considered (Lerner and Berg, 2015, 2017). There are also claims that plant health should be included in the considerations (Fletcher *et al.*, 2009). Also important is to consider how many aspects of life need to be covered. Should the definition apply only to physical aspects or also to mental, social and even spiritual aspects?

Health could also be considered on different levels, such as individual, population and ecosystem levels of health (Lerner and Berg, 2015). The first two are familiar to the disciplines of human and veterinary medicine and public health, but the third level, ecosystem health, is seldom recognized, and this makes One Health a more holistic transdisciplinary approach. In order to work with ecosystem health, biologists, environmentalists and others must be included in the approach. Sometimes, as in the One Health Commission and the One Health Initiative definitions, the term 'environmental' is used in the same manner as 'ecosystem'.

There are claims that the concept of health should be clearly defined for at least animals and humans (Stephen, 2014). Could there be a universal definition of health for, at least, both animals and humans? This might imply that the definition of health should be non-speciesist. In order to reach such a definition, one can follow two routes, either start from a human concept of health (top-down) and widen it to include animals, or one can find a common basic level for animals and humans (bottom-up) and define this as health. The first route might be too anthropocentric as well as not including enough species. The second route might be too basic for all aspects of human, and some species of animal, health (Lerner, 2019).

To define health bottom-up one starts by finding a common denominator. Mainly, these definitions are based on biology. A pioneer of One Health approaches, Rudolf Virchow, who defined health in terms of vital cells is an example of this. In Virchow's definition, health is considered present when enough cells are vital (Virchow, 1881). Species in all biological kingdoms consist of cells, and the definition of health could therefore easily be applied to all organisms. A more modern bottom-up version of health is Christopher Boorse's biostatistical theory of health, where health is regarded as species-specific functioning of biological organs (Boorse, 1997).

Top-down health definitions, on the other hand, start with definitions of human health and are expanded to other species if they share characteristics that are the foundation of these particular health definitions. These definitions are more holistic and encompass physical, mental and social aspects of an individual. An example of this is the WHO definition of health, covering physical, mental and social aspects of well-being. Nowadays, this definition has expanded to cover mammals and birds, at least in some fields of veterinary medicine (Lerner, 2017).

Is it possible to have a universal concept of health for all levels? A couple of aspects make this difficult. One should decide whether health should be defined as a state or as a process. Both ways exist. Health at the individual level is often defined as a state (Nordenfelt, 2006), while processes might be more important at population and ecosystem level. There might also be potential conflicts between these three levels. This is a similar problem as in ethics when individuals are compared to species or to ecosystems. Where should health apply? In the individual or outside the individual at an aggregated level such as the individual's population or the individual's ecosystem? In ethics, simplified, this question created the divide between animal ethics and environmental ethics (Lerner and Berg, 2015). Here, further discussions are needed.

There are many definitions of health present, and no consensus exists on what definition to choose. Recently, a thorough analysis of the idea that health should be a kind of balance was performed with a One Health perspective (Lerner, 2019). This study analysed which definitions based on an idea of balance could be suitable for One Health. Both bottom-up and top-down definitions were analysed. The conclusion was that there were promising aspects with some definitions, but there were also obstacles that made current definitions not fully applicable in One Health without some adjustments.

Despite the problems there are also other fruitful attempts to find universal non-speciesist definitions of health (Lerner, 2017). Lerner (2019) suggested criteria for what such a definition must fulfil to be suitable for the One Health approach. However, this area needs to be expanded and could be helped by a transdisciplinary merging of scientists from, for example, philosophy of medicine, sociology, animal welfare research, plant science and ecosystem science.

Summary

This chapter analyses the concept of One Health and focuses on the two words in the concept with the aim to better explain what the terms 'one' and 'health' refer to. First, making a distinction between the usage of the terms 'One Health approaches', which refers to all appraoches with a multispecies and multi- or interdisciplinary scope, and 'One Health', which refers to a specific kind of approach being made. Second, the One Health definition set forth in this book was compared to three other definitions of One Health, and pros and cons were identified. Additionally, the meaning of 'one' was discussed, showing the need for an interdisciplinary approach. Finally, the meaning of 'health' was shown to be complex, both regarding which definition of health to choose and on which level (individual, population or ecosystem) to apply it. A non-speciesist definition of health is needed, which could be either a bottom-up or top-down definition. Further discussions within the One Health approaches are needed.

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6 Transdisciplinary Research and One Health

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Introduction

One Health raises questions beyond the narrow view of health improvements based on medical interventions: its activities need to be understood in a context of local and global social-ecological changes, where outcomes are less certain (Zinsstag *et al*., 2011b). We need a range of disciplines to understand the context of health (Allotey *et al*., 2010). For this purpose, the starting point should not be a One Health approach, but the socially relevant health-related problem and its ecological dimensions. Other socially relevant problems are, for example, hunger, poverty, pollution and migration. In practising One Health, we seek practical solutions, which we most often cannot approach from an academic perspective alone. At this point academic scientists engage with non-academic stakeholders and their knowledge in research to solve practical problems and identify causes at their roots. Our experiences in intercultural and multilingual contexts (Nido Films, 2018) point towards a mindful, culturally and gender sensitive approach, paying particular attention to careful translation and interpretation between the different languages spoken (Zinsstag *et al*., 2019). The growing awareness of the need to embark in transdisciplinary processes to solve complex problems has invigorated the development and delivery of science-based policy in One Health in the past decade (Oura *et al*., Chapter 28, this volume; Rinchen *et al*., Chapter 29, this volume).

Trajectories of Transdisciplinary Research since the End of the 20th Century

Progressive fragmentation of the sciences into more and more specialized disciplines and thematic fields in the 20th century led to the perceived major risk that specialization could not recognize possible negative side effects for modern civilization. The growing awareness of such risks stimulated integrative approaches labelled ‘interdisciplinarity’ or ‘transdisciplinarity’ (see below for how we use these terms). Differences between basic, applied and transdisciplinary research, as specific forms of research, stem from whether and how different scientific disciplines and actors in the life-world are involved in problem identification and problem structuring, thus determining how research questions relate to problem fields in the life-world (Hirsch Hadorn *et al*., 2008). Transdisciplinarity has become a form of research with the possible association of any discipline. The number of publications using ‘transdisciplinary’ or ‘transdisciplinarity’ has grown rapidly since 1995. The Network for Transdisciplinarity Research (td-net, http://www.transdisciplinarity.ch (accessed 25 May 2020)) publishes these overviews on developments of transdisciplinary research. It was initiated in 2003 by the Swiss Academies of Arts and Sciences to support foresight and the dialogue between science and society. Transdisciplinarity has attracted growing international attention, leading to an international

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alliance for inter- and transdisciplinarity (http://www.itd-alliance.org (accessed 25 May 2020)) in Gothenburg in 2019 and development of a massive open access online course (MOOC) on transdisciplinarity (https://www.futurelearn.com/courses/partnering-for-change (accessed 25 May 2020)).

Hirsch Hadorn *et al*. (2008) in their chapter 'The emergence of transdisciplinarity as a form of research' and its section 'From dissociation to transdisciplinary orientation in the knowledge society', describe the history of transdisciplinary research from Aristotle's forms of knowledge to today. Transdisciplinarity plays such an important role in One Health that we consider it appropriate to summarize Hadorn's chapter to provide necessary background without claiming completeness. Natural science in the period since the 17th century has dissociated from philosophy and become concerned with empirical laws. Research is carried out by intervening into nature in technically equipped experimental settings. The concept of positivism postulates that observations are the only source of knowledge. There is a dissociation of science from practical knowledge, or what is also called the life-world. The term 'life-world' was introduced by the German philosopher Husserl (1859–1938). In the 19th century the science of society, called sociology, was created. Another German philosopher, Alfred Schütz (1899–1959), introduced the term life-world into sociology as 'social reality'. The social sciences and humanities put forward the need for interpretation of social and cultural phenomena from an historical perspective. Wilhelm Dilthey (1833–1911) advocated a hermeneutic paradigm to achieve an understanding of cultural ideals. Natural sciences attempt to explain natural phenomena, but hermeneutics attempts to interpret and assign a meaning to social and cultural phenomena from an historical perspective. The debate is about explanation versus meaning.

Sociology was confronted with the social crises of capitalism in the 19th century. The German sociologist Max Weber (1864–1920) recognized practical problems as a stimulus for scientific research. There is an ongoing debate regarding the relationship of empirical science to societal values. Scientists do not limit themselves to describe, for example, poverty; they consider poverty as socially unacceptable and thus do not make a descriptive, strictly scientific, statement, but a normative, value statement. Weber argued that empirical sciences are about what is either true or false, while the normative distinction in the sphere of values is that of right or wrong. Given the progressive fragmentation of the sciences into more and more specialized disciplines and thematic fields, emerging complex phenomena could no longer be recognized, which led to the development of systems theory studies and of multidisciplinary and interdisciplinary thinking. When a variety of disciplines collaborate in one research programme without integration of concepts, epistemologies or methodologies – but link research results – we speak of multidisciplinarity. Interdisciplinarity is also a collaboration of several disciplines, but concepts or methodologies are explicitly exchanged and integrated, resulting in a mutual enrichment (Flinterman *et al*., 2001; Darbellay and Paulsen, 2008) within scientific context.

Erich Jantsch (1929–1980) sees the triangle of university–industry–government as a 'transdisciplinary' triangle organized by general systems theory. In the second half of the 20th century natural resource crises emerged due to, among other forces, rapid population growth. The Brundtland Report from the United Nations World Commission on Environment and Development recognized in 1987 that the complexity of the interactions of a 'Risk society' (Beck, 1992) and unintended and poorly understood damage to natural resources and lives require systemic thinking across different academic disciplines and involving societal actors like communities and authorities. The United Nations Conference on Environment and Development in Rio de Janeiro in 1992 promoted sustainable development by involving people from civil society, the private sector and public agencies as actors in participatory deliberation and decision making. Addressing climate change is a formidable example showing the need for normative negotiation and co-producing transformational knowledge for practical solutions.

Social sciences and humanities became involved in activities such as technology assessment and ethical committees on morally sensitive technologies. Mittelstrass (1992) defines 'transdisciplinarity' as a form of research that transcends disciplinary boundaries to address and solve problems related to the life-world. Through scientists entering into dialogue and mutual learning with societal stakeholders, science becomes part of societal processes, contributing explicit and negotiable values and norms in society and science, and attributing meaning to knowledge for societal problem solving (Hirsch Hadorn *et al*., 2008).

Based on their historical review, Hirsch Hadorn *et al.* (2008) conclude that one can understand why transdisciplinary research is shaped by various lines of thinking and has a variety of definitions. We thus present here the definition derived by the same authors, which is based on a synthesis of what can be found in the literature:

> There is a need for transdisciplinary research when knowledge about a societally relevant problem field is uncertain, when the concrete nature of problems is disputed, and when there is a great deal at stake for those concerned by problems and involved in dealing with them. Transdisciplinary research deals with problem fields in such a way that it can: a) grasp the complexity of problems, b) take into account the diversity of life-world and scientific perceptions of problems, c) link abstract and case specific knowledge, and d) constitute knowledge and practices that promote what is perceived to be the common good.
>
> (Pohl and Hirsch Hadorn, 2007, p. 20)

Transdisciplinary research projects consist of different phases of intra-, multi-, inter- or transdisciplinary collaborations (Herweg *et al.*, 2012). The sequences and interactions of these different forms of collaboration need to be iteratively considered by the transdisciplinary team. For this process, aiming to tackle societal challenges and reaching academic success at the same time, several methods have been developed during the last few years (Pohl, 2018). The actors involved learn from each other (mutual learning) and they acquire a new type of learning (Tobias *et al.*, 2019). As research on these actors themselves has shown, there are specific characteristics that are mandatory for being successful in transdisciplinary collaboration (Guimaràes *et al.*, 2019).

Classical disciplinary knowledge is not sufficient in situations of high uncertainties like pastoralist societies facing complex social-ecological challenges (Seid *et al.*, 2016). Hence, we require a dialogue with involved stakeholders as an extended peer community. Funtowicz and Ravetz (1993) introduced the term of 'post-normal' science as a concept transcending classical disciplinary academic science, engaging in a dialogue with all who have a stake in technical and normative decisions on problem solving. Transdisciplinary approaches are thus a central element of generating an added value of One Health, progressively strengthening cooperation between human and animal health and other disciplines, between academic and non-academic actors (Zinsstag *et al.*, Chapter 2, this volume; Bunch and Waltner-Toews, Chapter 4, this volume). Next to post-normal sciences, analogous approaches to transdisciplinarity (that recognize the need to integrate disciplines and engage civil society in view of the relevance to the policy problem in question, but also recognize the complexity and uncertainty) are the Science of Team Science in North America, Integration and Implementation Sciences in Australia, and Public Engagement in Europe and elsewhere.

We can distinguish three forms of interdependent knowledge: (i) systems knowledge; (ii) target knowledge; and (iii) transformation knowledge. Systems knowledge relates to questions about the genesis and possible further development of a problem, and about interpretations of the problem in the life-world. Target knowledge relates to questions determining and explaining the need for change, desired goals and better practices, while transformation knowledge relates to questions about technical, social, legal, cultural and other possible means of acting that aim to transform existing practices and introduce desired ones (Pohl and Hirsch Hadorn, 2007). A transdisciplinary approach identifies and structures (providing an account of the state of disciplinary knowledge and actors in society involved in order to define the problem and raise research questions), analyses (providing adequate organization, and indicating which interests and circumstances to take into account) and brings results to fruition (embedding solutions into the social and scientific contexts, and testing the expected impact). Problem identification and structuring can overlap, which makes an iterative rather than a sequential approach more rational for achieving valid results. Unexpected and surprising results are to be expected (Hirsch Hadorn *et al.*, 2008).

Scientists are often overwhelmed by the amount of information in everyday practice and the lack of a common language in specialized fields of expertise. In inter- and transdisciplinary programmes researchers should have: (i) their own in-depth knowledge; (ii) general knowledge of the other disciplines involved; (iii) social and communication skills for the exchange between disciplinary researchers and actors of the life-world; (iv) respect for others; and (v) teamwork and cognitive (or synthesis) skills (Flinterman *et al.*, 2001). Thus, they need to have the mindset of a 'transdisciplinarian' (Guimaràes *et al.*, 2019).

Additionally, awareness of the multilingualism within the transdisciplinary team is essential. Transdisciplinary projects mainly consist of actors with various mother tongues and different forms of multilingualism, which can be classified into three types in transdisciplinary collaborations (Pelikan, 2019; Pelikan *et al*., 2019):

1. *Idiolect* – Every person has an individual idiolect, consisting of, for instance, mother tongue, dialect and terminologies. This means multilingualism not only appears between and within individual languages, but also within all of us.
2. *Intralingual multilingualism* – The difference between the styles of thought (Pohl, 2011) and worldviews of the actors involved, leading to various concepts and values that are manifested in language(s) and communication, can only be successful if all involved actors share a defined set of values and concepts – in their individual language. Within every language (and also lingua franca), specific terms are used for all these values and concepts. In addition to the translations between individual languages, intralingual translations are necessary – translations within individual languages. A mindful hermeneutic approach is necessary to understand and translate these concepts into shared understandings between all the cultures, disciplines, etc. involved.
3. *Interlingual multilingualism* – In multicultural and multilingual and multidisciplinary contexts, the involved project members speak different languages (e.g. English and Spanish), which leads to multilingualism of different individual languages, interlingual multilingualism. Translations play an important role, and the need for a shared language is obvious. However, 'as participants communicate in a common language, this may create the illusion that they also share a common culture' (van Mulken and Hendriks, 2017). But the implementation of one individual language (e.g. English) as a shared language, a so-called lingua franca, does not create a shared culture and even causes further difficulties. Some transdisciplinary projects cannot find a lingua franca, as not all actors involved share one individual language (Münch, 2002), and translations into a lingua franca and between other languages are often underestimated since they also deal with intralingual multilingualism.

These types of multilingualism play an essential role in terms of comprehensibility of the communication of and within transdisciplinary projects. Monolingualism by using English as lingua franca is practised quite often in academia, carrying the risk of losing multiple meanings about culture, behaviour, emotions and connotations and disciplinary approaches. Additionally, monolingualism may lead to power issues of differentiated knowledge acquisition: knowledge is not only transferred and acquired through communication, knowledge can also arise through writing – the so-called epistemic writing. Within the process of epistemic writing, the writing person acquires new knowledge while writing. This occurs in writing processes of different phases of projects (Pelikan, 2019), for instance during the data analysis, and less knowledge is acquired when one writes in a foreign language. Efficient language acquisition needs also to be enabled for illiterate partners, who are often part of the collaboration with local communities. In this frame, important power issues and ethical questions need to be discussed for avoiding 'epistemicide' (Bennett, 2015), the disadvantage of actors within the collaboration due to their mother tongue within transdisciplinary processes. The functional implementation of multilingualism needs to be planned to reduce power issues and epistemicide. Therefore, project communication needs to be considered from the outset and included in the budget – for every phase of the project. As an example, the project's budget needs to include translators who are familiar with the concepts involved and equipment to be implemented in all partners' meetings.

The awareness of these idiosyncrasies, typical of inter- and transdisciplinary collaboration, could increase the potential of partnerships to produce useful outcomes. Taking into account all the different styles of thought and socio-cultural backgrounds of the people involved, manifested in their cultures and languages leads to the concept of intercultural transdisciplinarity. Intercultural transdisciplinarity can be understood as the inclusion of different cultures (e.g national, disciplinary and ethnolinguistic) involved in the transdisciplinary research process by emphasizing and making use of the benefits of their interaction with each other, such as in cases of 'reverse innovation' (Zinsstag *et al*., 2019). This implies attempting to understand the explanatory models and associated values and preferences of all key cultures involved in the transdisciplinary group, what anthropologists refer to as the 'emic view' (Pike, 1967). The emic view consists of interpretations from the perspective of an insider of a given culture. Traditionally, scientists are trained to interpret data about the natural and social world studied, and to synthetize it in view of a specific chosen paradigm, thus creating *etic* constructs or explanatory models to simplify the complexity of observed reality (Headland *et al*., 1990). In this process between *emic* and *etic* views, one culture often reassigns significance over another's emic constructs, which can sometimes lead to a misrepresentation of a given culture's knowledge system or to their associated values and preferences being overlooked, potentially leading to a conflict. In pluriepistemic, multicultural settings, transdisciplinary collaboration requires all participants to bring forth their emic and etic explanatory models about the issue at hand and present them to each other, creating in the process many etic interpretations (e.g. traditional healers reinterpreting a biomedical doctor's explanations about a zoonotic disease, and vice versa). The challenge is to facilitate a process for dialogue where multiple emics of *self-representation* and etics of *otherness-representation* can find a common ground for mutual learning, reducing ethnocentric behaviour that leads to bias in research, and aiming towards co-creation of new knowledge to address the target problem (Berger-González *et al*., 2016). All these approaches need to be part of a concept for project communication (Pelikan, 2019).

Transdisciplinary Research in One Health and Ecohealth

Both quantitative and qualitative approaches enrich our knowledge. True interdisciplinary research programmes in One Health and on zoonoses control are few in number. With some strong exceptions (see Welburn and Coleman, Chapter 21, this volume), so-called 'socio-economic' or 'socio-cultural' studies on zoonoses are largely questionnaire based, including the knowledge, attitude and practice (KAP) studies, and are often led by veterinarians. These rapid appraisals have several shortcomings, particularly because they do not further describe the context (Allotey *et al*., 2010). New institutional arrangements between social and biomedical sciences are needed to establish interdisciplinary teams, which can be seen as the motor of transdisciplinary research (Whittaker *et al*., Chapter 7, this volume). Below we present a few examples of transdisciplinary processes in One Health and ecohealth.

Long-term iterative process in Chad to improve the health of pastoralists and their livestock

Livestock-keeping communities are often excellent observers and know the priority diseases of people and animals in their context. However, in rural and remote rural zones they are confronted with difficulties accessing health services (Danielsen and Schelling, Chapter 14, this volume). To improve health in a credible way in remote rural communities, all health aspects should be reviewed and interventions built on communities' and authorities' priorities in a participatory way. Within research partnerships between European and Chadian research institutes, we explored possibilities to improve access to services of mobile pastoralists in Chad, who were previously served by veterinary services but not human health. This aspect was then also one result of an interdisciplinary team including anthropology, social geography, medicine, veterinary epidemiology and microbiology. Other disciplines such as sociology and geography were associated in the further course of the programme with additional funding. Research results also included the absence of a local concept for zoonoses (Krönke, 2004) and that access to key pastoral resources and related conflicts with sedentary communities strongly influenced care-seeking behaviour (Wiese, 2004). Thanks to livestock holders' reports on perceived poor anthrax vaccine quality, contamination problems in local vaccine production were detected (Schelling *et al*., 2008). We used the community-based research results to initiate broader collaborations with authorities and scientific experts, and results were reviewed in the communities during focus group discussions and regional workshops to obtain a broader perspective from pastoralist men and women. The research hypothesis and objectives of the complementary studies were guided by the recommendations of the first national workshop in 1998. Indeed, one key recommendation – leading to an advantage of the programme compared with other single-sector studies – was that veterinarians must be associated because livestock, the most important element in the livelihood of mobile pastoralists, could not be excluded.

Repeated stakeholder seminars became crucial elements towards a transdisciplinary process. These allowed the scientists to engage with communities and their representatives and associations, authorities from the Ministry of Health (MoH) and the Ministry of Livestock Production as well as local authorities, technicians and staff, non-governmental organizations (NGOs) working with pastoralists, international bilateral and multilateral organizations such as the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) and donors (Léchenne *et al.*, Chapter 19, this volume). The consultative stakeholder seminars aimed to define priorities of the populations and the authorities jointly, formulating health service priorities from a range of options and readjusting ongoing interventions but also cross-checking the relevance of activities. Pastoralists could express their concerns and needs directly to the authorities and also voice non-health-related demands such as requests for new legislation on land use. The priority-setting process started from health-system-driven approaches – pragmatic in the sense that interventions could be carried out by the health and veterinary services and be validated by involved scientists – and moved incrementally towards the inclusion of other community priorities. The participants identified new research and intervention objectives and, consequently, trust and mutual respect were gradually built. The programme became the interlocutor between pastoralists and the authorities, and the communities were empowered to take their own initiatives (Schelling *et al.*, 2008).

In conjunction with the stakeholder workshop in 2005 a process of inter-ministerial planning of a national action plan to support nomadic communities in Chad started under the leadership of the Ministry of Planning in collaboration with eight other ministries (Fig. 6.1A). However, intersectoral negotiations with so many ministries proved to be too ambitious and were not feasible. The new course, where the MoH took the lead, turned out to be more operational. During the workshop in 2013, the MoH announced the creation of a directorate for the health of mobile pastoralists. Activities that are implemented as a result of the transdisciplinary process, particularly the joint human and animal vaccination campaigns – currently in transfrontier zones – are maintained and led by the government. There is also a presidential decree for full Expanded Programme on Immunization (EPI) coverage for pastoralist children along with polio vaccination days. The 'Association des jeunes nomades' is more active and prominent than ever, regarding the problem of pastoralists as an institutional problem. These dynamics of pastoralist representation would hardly have been possible some years earlier when only a few pastoralists had received higher education. Finally, the stakeholders voiced a desire to seek new innovations such as use of mobile technology to assess demographic and health parameters of pastoralist families and their livestock (Jean-Richard *et al.*, 2014).

The iterative problem-oriented programme aimed at improving access to health care for the nomadic pastoralists of Chad started with little information on important health issues. However, ownership by the communities for interventions was achieved by their participation in knowledge generation as equal partners, together with local

Fig. 6.1. (A) Transdisciplinary stakeholder workshop on the shores of Lake Chad, bringing together national Chadian authorities, pastoralist communities and scientists. (B) Stakeholder workshop in Gode, Somali Regional State, Ethiopia. Pastoralist women, health professionals and scientists discuss health care in their communities. Photos courtesy of J. Zinsstag.

authorities and scientists in a transdisciplinary approach. Unexpected outcomes emerged, for example the pastoralist communities organized themselves to provide schooling for their children, which received support from UNICEF. They have also stated that their overall security improved substantially. Generalizations for other settings can hardly be made, but where communities interact with authorities in a process to identify acceptable institutional and legal frameworks, arrangements for social service development in a given context can be achieved. The long-term commitment of all partners continues and has broadened the scope of research to other mobile communities, for example in Somali Regional State in Ethiopia (Fig. 6.1B) as well as seasonal workers and inter-provincial migrants in Vietnam.

Surveillance and response to zoonotic diseases in Maya communities of Guatemala: a case for One Health

The overall aim of a project among Maya communities in the Petén region of Guatemala was to promote a transdisciplinary One Health approach for developing a novel and culturally appropriate surveillance and response system for zoonotic diseases. Participants of a project inception workshop in September 2016 represented: (i) programme and policy-oriented government officials from the Ministries of Health and of Livestock (35%); (ii) Guatemalan academics from the Universidad del Valle de Guatemala interested in zoonosis research (28%); (iii) community representatives including Maya elders from the ACGERS Council seeking to improve health conditions in their towns (17%); (iv) Swiss academics interested in developing surveillance systems using a One Health approach (10%); (v) private industry (Tigo telecommunications company) looking at potential cell phone applications (7%); and (vi) an international development cooperation (3%).

Key steps in a transdisciplinary process are to clarify the interests of the initially identified stakeholders involved, openly discuss these interests, and jointly agree on which ones will be addressed by the forming partnership. Equal footing of all partners was not assumed to emerge naturally in the discussions. Therefore, social scientists analysed how multiple conditions of the project's partnership related to ethnicity, language use, world-view (cosmology), values (axiology) and epistemology (all of which encompass 'culture') affected the participation of stakeholders in the process and subsequent outcomes of the project. Diverging initial interests coexisted according to literacy and education of participants, economic status, degrees of rurality, and ethnic background, and varied also according to participant's position in hierarchical power structures. Backward planning was used to understand the steering team's assumptions during different project phases. Figure 6.2 shows the backward planning process starting from the intended goal of having all partners co-define the final project objectives, later assessing underlying assumptions. These were then translated into questions which guided the verification process.

From the initial analyses, it was observed that communication across groups was challenged by linguistic diversity, with Spanish as the primary

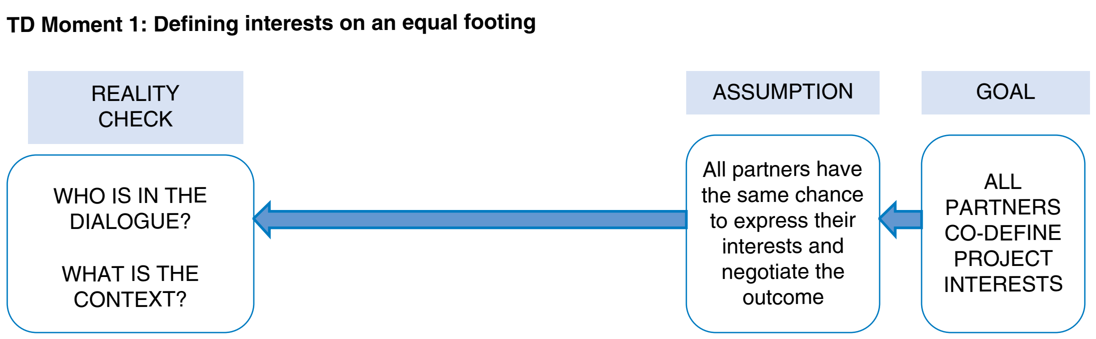

Fig. 6.2. The backward planning process. This was used as transdisciplinary (TD) Moment 1, one of two reflexive moments included in the workshop held at the inception of the One Health project aimed at developing a culturally appropriate surveillance and response system for zoonotic diseases in Maya communities of Guatemala.

mother tongue of 77% of participants, followed by Maya Q'eqchi' (13%), Swiss German (7%) and English (3%). Knowing that language use reinforces or leverages existing power differentials and the ability to put forth one's interests (Brenneis, 1988), on-site translation between Q'eqchi', Spanish and English was organized during the workshop. Multilingualism was the most immediate challenge to address to ensure equal footing of participants. Context analysis demonstrated a more pervasive problem, that of historical exclusion of indigenous groups and a recent post-war setting that eroded the social fabric, with negative effects in inter-ethnic relations (Flores *et al*., 2009). Having looked at intersectionality issues, the coexistence of multiple layers of identity that intertwine to create further exclusion (Fiorati *et al*., 2018), it became evident that factors of ethnicity, rurality, poverty, literacy, gender roles and seniority enhanced power differentials among participants. Mutual trust was not a given and merely being invited to the workshop did not guarantee equal participation. Moreover, a lack of interest in mutual learning due to ethnocentric behaviour had been documented in a similar context (Flores *et al*., 2009). In response to this contextual complexity, the workshop was planned to include two reflexive moments to make participants aware of the multiplicity of knowledge systems and coexisting values and to realize its richness. One exercise required participants to draw or write names of animals that they liked having around, feared, respected and found useful. Results were shared in small groups, which then presented their agreements to the plenary. This allowed participants to see how their livelihood context and culturally determined values shaped their views, therefore becoming aware of how diverse the human–animal interface was among participants. Another exercise showed six pictures of symbols and situations that belonged to either biomedical or Maya medical knowledge systems, and asked participants to write down what they saw. For example, when projecting a picture of cells under a microscope, participants with a biomedical training identified it easily, while Maya participants described it as a close up of a fungus that grows in corn or water droplets. Similarly, when presenting the Maya Kajtzuk (an ancient symbol with multiple layers of meanings), only those with knowledge of Maya spirituality could recognize it, while others imagined it was a strange Catholic cross. The exercise made participants aware that they were using their knowledge systems as a reference to interpret the same objects. This moment was used to introduce the concepts of emics and etics, commonly known as the insider's and outsider's views on an issue. A general awareness concerning the added value of exploring concepts from diverse points of view was reached, prompting from then onwards, community representatives to share their views more comfortably.

After gaining awareness of emic interpretations, the participants were engaged to discuss their genuine interests and demands to enter the transdisciplinary (TD) partnership. To avoid one sector taking over the discussion, and to prevent one group speaking for another (ventriloquism) (Spivak, 1988), each person had three flashcards upon which to write their interests. Once completed, participants joined groups by sector (academic, government, etc.), agreed on common aims, and jointly presented the flashcards they had made to the plenary. Each interest was discussed and placed in a three-column matrix according to: (i) which interests would be addressed by the TD partnership; (ii) which would be referred to other institutional efforts (e.g. initiating contact with an NGO building a school); and (iii) those not to be addressed at all. From this participatory exercise, clarification and agreements of the project's expectations and limitations emerged. Allowing multivocality leveraged traditional power differentials and enabled usually excluded concerns of indigenous participants to be taken into account. Throughout the course of the project, participants understood the value of diversity and equal representation of Maya and biomedical knowledge systems, so by the last of four TD workshops, held in May 2018, community leaders accounted for 31% of participants, with more women participating.

In summary, offering a platform for balanced participation required modulating power differentials through three mechanisms: (i) inducing self-reflexivity of participants to acknowledge diversity of experiences (the exercise with animals); (ii) participants' understanding of the difference between emic and etic constructs leading to bias or mutual understanding (the culturally significant picture exercise); and (iii) acknowledging the value of diverse views to address zoonosis as a health topic (through translation and use of flashcards for equal representation of views). Once these three preconditions were met, a successful negotiation of interests (avoiding power overrides) was possible. Figure 6.3 shows

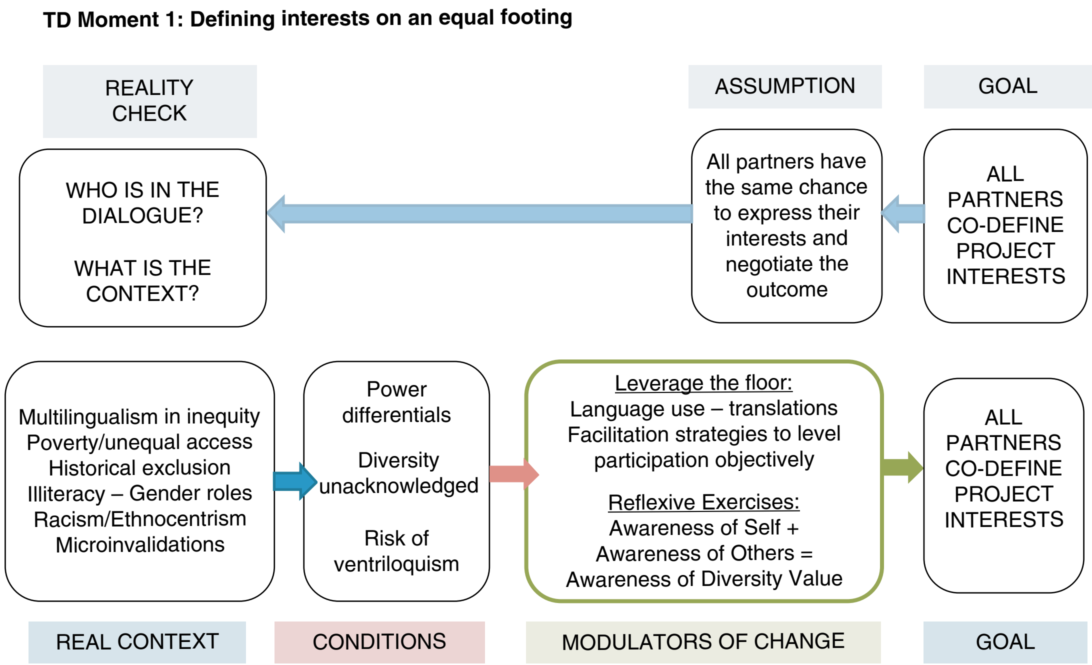

Fig. 6.3. Adapted reflexive approach derived from backward planning used to develop specific tools as modulators of change, in order to achieve the desired goal (overlaid with Fig. 6.2). For each condition, workshop participants were asked to define the needed modulator of change.

the adapted reflexive approach derived from backward planning used to develop specific tools as modulators of change, in order to achieve the desired goal.

This reflexive process was used throughout the project life to make sure that the team went from a multicultural approach where many 'cultures' or knowledge systems coexisted without cross-over understandings, towards an intercultural approach where mutual learning and knowledge co-production was promoted. The pragmatic value of this approach is seen in the following outcome.

A surveillance system for detecting signs of two targeted zoonoses was implemented. In order to increase sensitivity, case definitions for respiratory, febrile and diarrhoeic syndromes were initially developed by epidemiologists and presented to the multicultural academic team. Maya health personnel discussed among themselves how erroneous the biomedical terms were according to local understandings. Noticing a reluctance to publicly contradict a senior epidemiologist, social scientists developed an exercise inviting each team member to propose new categories for surveillance from their own emic perspectives. What followed was a discussion on 23 different Maya Q'eqchi' terms that local indigenous people could use to define different types of fever, diarrhoea or respiratory illness. This elaborated range of local terms was used to prepare research instruments to test how local people perceived each syndrome. Results of these analyses were later used to develop materials for communication campaigns for explaining at household level how surveillance would operate. Most importantly, it helped Maya health staff unify recruitment criteria for Maya patients for whom case definitions of the protocol had to be completed. Throughout the project the field team met on a regular basis to discuss new emic categories that emerged during interactions with patients. This increased the cultural pertinence in medical response and provided culturally relevant 'danger signs'. For example, whenever a patient indicated they had 'susto' or 'itzel yax', the health team knew it to be an illness in dire need of attention. We could show that awareness of emic categories of disease reduced misconceptions leading to erroneous interpretations of medical data, while it increased mutual understanding between representatives of different epistemic systems (Berger-González *et al.*, 2016; Hitziger *et al.*, 2017). However, this awareness did not occur without facilitation, as depicted in Fig. 6.4. Communications that nullified the experiential reality or identity of indigenous persons, called microinvalidations (Christopher *et al.*, 2008), and attitudes of 'cultural discounting' were observed. The latter were based on the assumption that indigenous partners were passive recipients of knowledge to 'improve' their livelihoods and could not contribute usefully to the research. The critical analysis of inter-ethnic relations served as a base to modulate spaces for equal participation, which included constant reminders to use all languages, to address all relevant emic categories, and to promote respectful listening skills. This facilitated multidirectional conversations rather than unilateral information transfer. Health teams learned to replicate this process with patients and were rewarded with rich insights into Maya healing systems and a better understanding of perceived desirable outputs in collaborating with the public health system.

Transdisciplinary process in the Jigjiga University One Health Initiative (JOHI)

JOHI is a research-development project currently implemented in the Somali Regional State of Ethiopia to create innovative integrated health systems for improvement of health and well-being of pastoral communities. It is a 10 year (2015–2025) project co-funded by the Swiss Agency for Development and Cooperation (SDC), the Swiss Tropical and Public Health Institute (Swiss TPH) and the Jigjiga University (JJU). The project includes three main actors: (i) JJU for legal status and curricula; (ii) Armauer Hansen Research Institute (AHRI) for policy and research support and technical collaboration; and (iii) Swiss TPH providing technical expertise.

Setting up the project followed a process of extensive consultations with communities, authorities and technical experts within participatory processes in Jigjiga city and Gode, the main city of the study area in Adadle district (woreda). A preparatory workshop took place between representatives of the JJU, AHRI and Swiss TPH together with SDC staff in September 2014. The inception

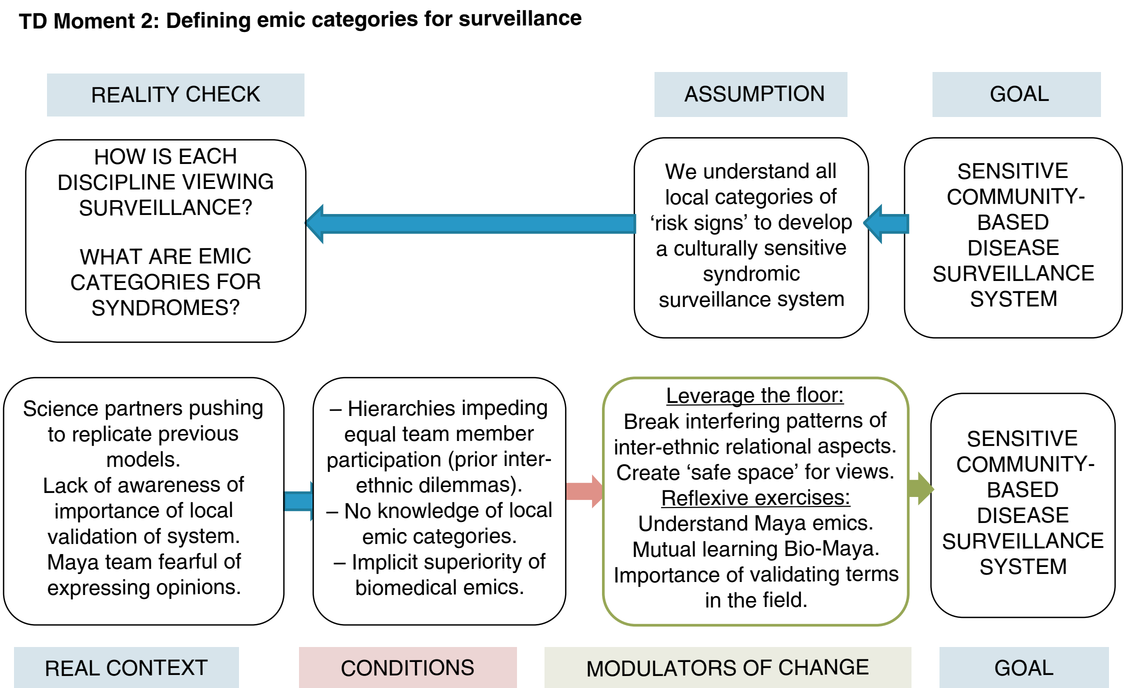

Fig. 6.4. Backward planning tool employed to increase sensitivity of the surveillance system implemented for detecting two targeted zoonotic diseases in Maya communities of Guatemala.

phase aimed to prepare the full project document. A stakeholder workshop in March 2015 in Jigjiga identified the main priorities of communities and representatives of the regional government bureaus. A first batch of PhD and MSc students went to be trained at Swiss TPH in the fields of human nutrition, midwifery, tuberculosis, animal health and rangeland management. Upon their return, the students prepared their field work. In June 2016, the supervisors together with the project accountant visited JJU and the field site in Adadle woreda and met the local authorities and communities.

The field studies and data collection were done as one interdisciplinary team in the Adadle woreda from July to August 2016. The second batch of students was similarly elected, by interviewing candidates. A stakeholder meeting was held in Gode at the end of February 2018, and first decisions were made on proposed interventions based on the research in tuberculosis control, integrated surveillance and response adapted to pastoralists and water and sanitation. Unexpectedly, the mayor of Gode requested support for an abattoir and better meat markets. A steering committee and a further stakeholder workshop were held in Jigjiga in May 2018, and the proposed interventions were further discussed and approved. Interventions were subsequently implemented, and upon the first results, communities and authorities met again with the interdisciplinary research team to discuss next steps together. Communities were faced with the challenge of financing fuel for emergency ambulance services, so JOHI assisted communities in organizing to raise emergency funds. Additionally, the project team engaged in developing an abattoir and a safe meat marketing system, taking up local priorities that were not in the initial plans of the project. All actor groups remain involved in the sharing of knowledge and expressing priorities for further health development actions.

National and regional priority setting in health and food safety

Regarding societal questions about health, priority setting is not only needed in research and action in specific contexts but also on national and regional levels. As such, new public engagement processes can be initiated. For example, the European Food Safety Agency (EFSA) initiated an integrated approach towards risk assessment with a special focus on human health and the whole food chain, as well as on science-based interventions to lower consumer risks. They regularly consult with scientific panels to address complex, multifaceted questions of risk and experiment with how to engage the broader public. This consultation process revealed, among other things, increasing public concerns about the sustainability of livestock production systems, acceptability of food quality and animal welfare issues (Berthe *et al.*, 2013). Donors are encouraging low- and middle-income countries to set up processes of public participation in health-sector priority setting. A recent review, however, showed that to date there is little evidence on how to do this in a less costly way. The authors of the review propose that some of the substantial resources needed for a nationwide public engagement could be used to strengthen the evidence for what works within the realities, using small-scale, community-driven trials (Alderman *et al.*, 2013).

Transdisciplinarity in ecohealth

Transdisciplinarity is well embedded in ecohealth to tackle the non-linear systems dynamics (Bunch and Waltner-Toews, Chapter 4, this volume). The International Development Research Centre framework implies not only a transcendence of disciplines, but also the participation of scientists, communities and policy makers in research (Lebel, 2004). Particular attention is given to gender and social equity and putting knowledge into action through policy change, interventions and improvement of practices (Charron, 2012). Examples of transdisciplinary processes are presented in Charron (2012), Veterinarians Without Borders/ Vétérinaires Sans Frontières Canada (VWB/VSF Canada, 2010) and in Bunch and Waltner-Toews (Chapter 4, this volume). Parkes *et al.* (2005) exemplified the value of transdisciplinarity for emerging infectious diseases. They concluded that with transdisciplinary integration and innovation for infectious diseases it may be possible to harness the good will and teamwork established during an emergency in order to address health issues that develop more slowly. With emerging health threats, the social-ecological and political contexts of global health foster integrated conceptual frameworks and disease control measures (see also Gallagher *et al.*, Chapter 24, this volume). Although complex understandings of social and ecological systems may be informative and better reflect the uncertainty of real life, such approaches may be challenged on the basis that they often do not lend themselves to straightforward, rapidly implemented policies or interventions.

Disciplines and Approaches are Not Static: Intermediary Conclusions

Transdisciplinarity emerged as a form of research at the end of the 20th century because separated disciplines could not grasp the complexity of, for example, the impact of new technologies and natural resource depletion. Such issues could not be tackled from the sphere of individual disciplines. We see health as a life-world problem and believe that transdisciplinarity should be at the heart of One Health studies leading to improved health of people, animals and the environment. The examples in this chapter show that the engagement of other than academic knowledge can lead to problem solving and innovation, as well as unexpected outcomes. For enabling this, efficient project communication including multilingualism is mandatory and needs to be planned from the outset for every phase of the project. Taking a One Health approach can promote development of good partnerships between government agencies as well as engage the public and industry stakeholders in the development and delivery of policy (Rinchen *et al*., Chapter 29, this volume). It can further increase equity and effectiveness of interventions at national and subnational levels, because equity can only be defined within a broad transdisciplinary partnership between communities and authorities governed by mutual trust and security. This is similar to what is promoted in the 2008 Report of the WHO Commission on Social Determinants in Health that recognizes civil society as a champion of equity (Jackson *et al*., 2013). Health equity, in turn, is part of sustainable development and hence directly linked to environmental sustainability and social justice (Zinsstag *et al*., 2011a).

Participatory stakeholder processes, as discussed above, seemingly have huge potential for practical problem solving but also bear risks. These include raising expectations too high for outcomes of the process and choosing certain health-related outcomes over others such as poverty alleviation (which implies ethical considerations), the stakeholders engaged are not representative for the relevant problem area, and there may be biases in the process due to power relationships, such as dominance of academia and gender issues. These few examples show how important it is to involve social scientists and communication specialists in stakeholder processes and to carefully document the process right from the outset.

Complexity, uncertainty and ambiguity in health and other life-world problems are obviously challenges. How do we deal with corruption or the discrepancy between investments in development of sophisticated, new technological tools, when we do not manage to effectively deliver existing adequate tools, such as measles vaccination? We can deal with complexity by interdisciplinary expert inputs, although we may invite a suboptimal panel of disciplinary experts. Each researcher and actor may locate the problem in an alternative 'world of relevance'. Validation and quality control may help. Validation of non-scientific knowledge and explanations is a crucial and challenging aspect of knowledge integration within transdisciplinary research. Because different types of explanation play a role, different validation criteria have to be met, both through problem formulations and solutions found. Sometimes a non-scientific explanation can be tested as a hypothesis in a further research process. A continuous dialogue between the parties involved is required, with feedback loops for cross checking previous assumptions, insights and demands (Flinterman *et al*., 2001). Social scientists appear best situated to monitor the process and identify possible shortfalls that need corrective actions.

Researchers are challenged to cross the boundaries between human and natural sciences to generate results that could not have been attained using a disciplinary or sectoral approach alone. Scientists trained for many years in one discipline must first learn to acknowledge the strengths of other approaches. University curricula, however, rarely enable scientists to communicate with other disciplines, and researchers first need to acquire their own experiences and skills (Conrad *et al*., 2009; Min *et al*., 2013). Max-Neef (2005) wrote that this should not represent a problem as long as the higher education received was coherent with the challenge. This is, unfortunately, not the case, since monodisciplinary education is still widely predominant in all universities.

It is encouraging to see that donors explicitly ask for inter- and transdisciplinary research. However, the establishment of these processes requires some additional investments, and donors do not yet readily give more time or money. In any case, transdisciplinary research with its iterative cycles between innovation, application and validation is an integral part of One Health approaches.

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7 The Role of Social Sciences in One Health – Reciprocal Benefits

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Introduction

This chapter discusses the role of social sciences in developing a deeper understanding of diverse perspectives of health and illness in animals and humans, as well as in contributing to improve services and programmes using a One Health approach. Drawing on evaluated and ongoing examples from various countries, the authors demonstrate the added value of social sciences to address common local or global health problems using a One Health approach. The presentation and discussion of these examples allows for an exploration of various key aspects, ranging from diverse understandings of health risks, protection, responses, implementing interventions and health communications as well as questions of equity of access and benefit. Theories and approaches in anthropology and other social sciences frame the discussion. This analysis adds further value to social sciences' contribution to One Health and One Health's contribution to social sciences in research and in programme implementation.

Background

Rüegg *et al*. (2018) note that:

> Many current health challenges, such as spread of zoonotic infectious diseases, environmental pollutants, antimicrobial resistance, climate or market-driven food system changes with consequences on food and feed supplies, malnutrition including obesity and many more arise from the intertwined spheres of humans, animals, and the ecosystems constituting their environment.
>
> (Rüegg *et al*., 2018, p. 2)

They argue that such wicked problems require transdisciplinary and integrated approaches that take a systems approach, and that One Health provides such a framework.

A call for social science contributions to One Health is not new. As Dentinger (2017) has shown, Calvin W. Schwabe's pioneering work built on, and was reflected in, his efforts to understand the tapeworm *Echinococcus granulosus* as a biological and a cultural phenomenon, shaped by social relationships. In his studies in Beirut, among the Turkana in Kenya and later in California between 1956 and 1975, Schwabe expanded on the parasitological research tradition of examining biological host–parasite interactions in his explicit inclusion of social behaviour and cultural practice.

Since then, many natural scientists have emphasized the importance of human behaviour and cultural practices, for example for understanding risk exposure, transmission routes and the development of behaviour change interventions. Robertson and Thompson (2002) pointed to the need of educating dog and cat owners for managing enteric parasitic zoonoses in humans and their animals. The parasitologist Macpherson (2005) drew attention to the pivotal role human behaviour plays in the macro

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and microepidemiology of emerging or re-emerging parasitic diseases. The entomologist Gillett (1985) discussed the forgotten factor – human behaviour – and the complex relationships that exist between human behaviours and public works, urbanization, packaging, agricultural practices – and the transmission of vector-borne diseases. Dung *et al.* (2007) investigated the epidemiology of fish-borne zoonotic trematodes in Vietnam and suggested that behavioural factors warrant greater collaboration between epidemiologists and anthropologists in designing approaches for mitigating risk in a population with great resistance to change in eating habits. In discussing integrated rabies control, Lechenne *et al.* (2015) highlighted the importance of understanding the ecology of rabies, animal behaviour and human beliefs and behaviours in order to have effective programmes. Wildlife scientists Alexander and McNutt (2010) used data from a comparative study conducted in Kenya and Botswana to investigate the relationship between divergent cultural practices of pastoralists and contact between domestic dogs and African wild dogs. Based on this study and other examples, they developed a conceptual model of the potential influence of human behaviour on pathogen emergence at the human–domestic animal–wildlife interface and call for greater inclusion of the social sciences in emerging infectious disease research.

The outbreaks of SARS (severe acute respiratory syndrome), MERS-CoV (Middle East respiratory syndrome-related coronavirus), Ebola and Zika have further highlighted the need for social science approaches and actions. However, in 2017, the World Health Organization's (WHO) Health Emergency Programme and the Wellcome Trust noted that:

> Medical anthropologists and social scientists have been used to investigate and manage disease outbreaks, but social science interventions are not yet systematically used in all health emergencies, nor are social scientists trained to work with response teams effectively.
>
> (WHO, 2018)

To address this concern a consultative meeting was organized, bringing together 72 experts and partners from more than 40 agencies (WHO, 2018).

Since the first edition of this book (Whittaker, 2015; Zinsstag, *et al.* 2015), there has been an increase in publications on social science research in the field of One Health. This includes special issues in the journals in *Social Science and Medicine* (2015) and *Medical Anthropology Theory* (2018). A particular focus has been the role that social science inputs and insights can play in supporting health security issues like major infectious disease outbreaks.

This chapter discusses several approaches that expanded the One Health research and interventions to include social and cultural dimensions. The first set of approaches frame the research interest and concerns theoretically and practically in the disciplinary context of parasitology, epidemiology and other natural and public health sciences, even if they address social and cultural dimensions of the phenomena under study. This mirrors the fact that, in spite of its programmatic emphasis on interdisciplinarity, the biological paradigm clearly dominates the ways in which pathways to improve human, animal and environmental health are framed. The second set of approaches offer more opportunities for contributions and engagement that move theoretical and empirical concerns of the social sciences into the foreground of One Health research and interventions.

Social science can also inform and stimulate reflectivity of practitioners and researchers, to ensure a 'more holistic approach to joint problem solving and collective knowledge development' (Cole, 2017, p. 127). Transdisciplinarity, one of the pillars of One Health, behoves us to embrace local and indigenous knowledge, and not privilege Western science knowledge over the vast cultural continuum of knowledge (Schelling and Zinsstag, 2015).

Examining Social and Cultural Aspects of Human–Animal Interactions

The well-known public health tool of the knowledge, attitude and practice (KAP) survey, also called the knowledge, attitude, behaviour and practice (KABP) survey, is widely used in One Health research. Most KAP surveys use predefined questions and the format of a standardized questionnaire to discover characteristic traits in knowledge, attitude and behaviour about health risks, disease and ill health related to religious, social and traditional factors (Médecins du Monde, 2012). The underlying assumption is that these factors may be the source of misconceptions or misunderstandings that often represent obstacles to behaviour change. Numerous KAP surveys have been conducted in response to the Ebola outbreak in West Africa, for instance in Guinea (Buli *et al.*, 2015), Nigeria

(Iliyasu *et al.*, 2015) and Sierra Leone (Jalloh *et al.*, 2017). For example 3 months into the 2014 Ebola outbreak in Sierra Leone, Jalloh and colleagues (2017) conducted a national KAP survey. They found a high awareness of Ebola among all respondents. Without being prompted, 60% of respondents correctly cited fever, diarrhoea and vomiting as signs/symptoms of Ebola. Most respondents knew that avoiding infected blood and bodily fluids (87%) and contact with an infected corpse (85%) could prevent Ebola. But they also found widespread misconceptions, for instance the belief that Ebola can be prevented by washing with salt and hot water (41%). Nearly all respondents (95%) expressed at least one discriminatory attitude towards Ebola survivors. Unprompted, self-reported actions to avoid Ebola infection included handwashing with soap (66%) and avoiding physical contact with patients with suspected Ebola (40%). The findings of Jalloh and colleagues directly informed the development of a national social mobilization strategy in the early stages of the epidemic.

Although KAP surveys address topics that are of key interest to social scientists, they have not been developed for research in the social sciences but to conduct operational or implementation research in the field of family planning and populations studies (Launiala, 2009). Since then they have become increasingly popular, mainly for practical reasons; they can be used for low-cost rapid assessments by researchers with little or no social science background (Manderson and Aaby, 1992). At the same time, they have been criticized by social scientists and public health specialists mainly because the underlying assumptions are based on common sense and highly simplified psychological theories about the relationship between knowledge, attitude and behaviour and completely disregard the importance of contextual influences (Manderson and Aaby, 1992; Launiala, 2009; Muleme *et al.*, 2017).

More sophisticated models, such as the behaviour change wheel (BCW) (Michie *et al.*, 2011), which is grounded in a synthesis of psychological and sociological theories, have not, to our best knowledge, yet been used in One Health research. Although the BCW approach also takes as self-evident that biomedical knowledge, attitude and practice provide the golden standard for health improvement, it opens a space for studying what study participants do in real life – not just what they should do – and how their thinking and acting is shaped by the particular context in which they live.

Contextual influences are often conceptualized as social determinants of health, i.e. 'the circumstances in which people are born, grow, work, live, and age', and the wider set of systems and forces: 'economics, social policies, and politics' (CSDH 2008, p. 35). Woldehanna and Zimicki (2015), for example, have proposed an expanded One Health model that highlights the social and cultural determinants of human–animal interaction on the local level, with a focus on emerging viral diseases transmitted from animals to humans by direct or indirect contact. The key determinants they have identified are: (i) biological characteristics of individuals, for example gender; (ii) social characteristics of individuals, households and communities, including norms, livelihood systems and settlement patterns; and (iii) at the public policy level, local and international governance and politics (Fig. 7.1).

The newly emerging animal and human infectious diseases arise from, and are spread by, a multitude of social determinants and ecological causes interacting at multiple scales, from the local to the regional, national, international to global levels, and across diverse domains. As Weiss and McMichael (2004) have argued these changing contexts are due to increases in population size and density, urbanization and human encroachment on forests and wildlife, poverty, the increased number and movement of people, food and animals around the globe, and conflict and warfare.

Much attention has been focused on identifying the environmental, ecological and social dynamics underlying epidemic outbreaks of emerging zoonotic diseases like Ebola or Nipah. The Nipah virus, for instance, emerged in Malaysia in 1998 when deforestation destroyed the fruit bat habitat. The bats moved to trees near livestock pens where they spread Nipah to pigs, from which humans were subsequently infected. The intensification of pig farming associated with the spillover of the virus from bats to pigs to humans was backed by companies and land deals and by broader economic shifts in regional stockbreeding underpinning local dynamics (Epstein *et al.*, 2006; Otte and Grace, 2012; Pulliam *et al.*, 2012). In later outbreaks of Nipah virus infections in Bangladesh and India, no clear evidence of transmission through pigs has been found. Rather, drinking traditional liquor made from date palm sap contaminated by bat excreta was one of the main sources of infection (Luby *et al.*, 2006).

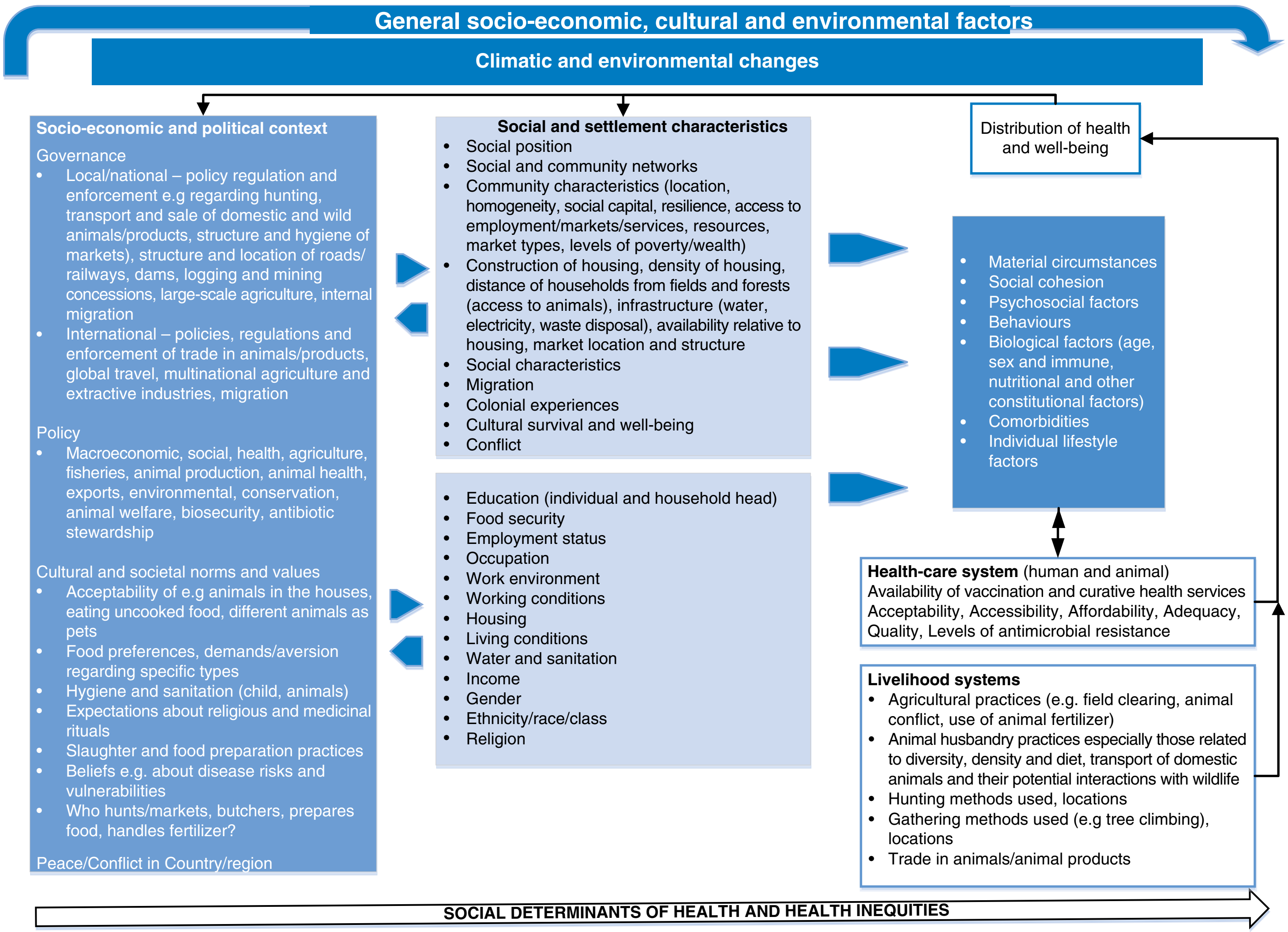

Fig. 7.1. Socio-cultural determinants of One Health. Adapted from Dahlgren and Whitehead, 2006; CSDH, 2008; Woldehanna and Zimicki, 2015.

Other studies have shifted the attention from epidemic outbreaks attracting high media attention to endemic and neglected zoonotic diseases. They have examined the complex interactions of poverty and ecosystems in settings where zoonotic transmission usually occurs. Such transmission is often associated with rapid environmental and land-use change and the close contact between humans and wild and domestic animals (Okello *et al*., 2014). This analysis of the zoonotic transmission takes diverse and context-specific pathways into account (Cunningham *et al*., 2017).

Complementary to studies emphasizing a contextual analysis of social determinants, comparative research delving in depth into one determinant, such as gender, across diverse settings also contributes to expanding the social One Health agenda, as illustrated by the following case study of a gender analysis of food safety (Case study 1).

Designing and Conducting Reflective and Participatory Social Science Studies and Collaborations in One Health

In their introduction to a special issue of *Social Science & Medicine* on social science engagement with the One Health agenda, Craddock and Hinchliffe (2015, p. 1) claim that 'without proper

Case study 1. How understanding gender can contribute to understanding and improving food safety. Contributed by Delia Grace, International Livestock Research Institute, Nairobi, Kenya.

Background

Food safety is a One Health issue. Foodborne disease (FBD) has a health burden comparable to malaria, HIV-AIDS or tuberculosis (Havelaar *et al*., 2015). The majority of the quantified causes of FBD are zoonoses and animal source food is an important source of illness (Grace, 2015). Most FBD burden falls on low- and middle-income countries (LMIC) and is the result of food purchased in wet or informal markets where the poor buy and sell.

Motivation for research

To improve food safety, we first had to understand it, and that meant identifying who was involved in making food risky or safe and their knowledge, practices and motivations. We knew women and men in LMICs have important, but usually different, roles in producing, processing, selling and preparing food. We hypothesized that these roles, as well as biological differences between men and women, may have negative and positive impacts on their health, and also lead to differences in health outcomes. This case study summarizes findings on gender roles, risks and opportunities from studies in 20 informal livestock and fish value chains in Africa and Asia (Grace *et al*., 2015).

Findings

Men were seen as having greater responsibility for keeping cattle, capturing fish and market-oriented production, giving them opportunity for income generation. Where value chains had an important processing stage, this was usually dominated by women (e.g. smoking or drying fish and producing traditional dairy products in West Africa). In all the value chains studied, the majority of meat and fish was sold in small-scale, traditional markets (which may also be called 'informal' or 'wet' markets). In such markets, women sell fish and poultry, but meat is typically sold by men (Vietnam was an exception). Overall, this means women were more exposed to occupational hazards such as chemicals and risk of injury. On the other hand, participation also increased their access to food and income. As processing became modernized, the role of women often declined.

In all the case studies, women were responsible for preparing and cooking food for family consumption within the household. Men's and women's consumption within the household was generally reported to be similar. There was a tendency for women to consume riskier foods such as offal. However, in many cultures, there were taboos about pregnant women eating risky foods such as tripe and dog meat, which may have reduced risk. Moreover, men tended to consume more meat and fish outside households, often in outlets which also sold alcohol: this exposed them to higher risk of meat-borne disease. In most countries, milk was given preferentially to children.

Gender analysis showed how women and men carried out different activities, which led to different health risks. In around half the value chains, women were more at risk and in half men were more at risk. Understanding this helped develop gender-sensitive interventions that would work for the gender most at risk. Our finding that when value chains become more formal, they tend to exclude women who dominate more traditional value chains, drew attention to a possible unintended consequence of modernizing food systems. Such insights into social dynamics can help ensure development is inclusive and ultimately more effective.

social science engagement, the One Health approach is at risk of derailment'. In order to increase the efficacy and legitimacy of the knowledge produced, their argument goes, One Health research has to: (i) recognize and respect diversity regarding approaches to and understandings of health; (ii) acknowledge and appreciate social and cultural difference; (iii) analyse and take into account uneven power relations; and (iv) pay attention to how associations between disparate social worlds are configured. We affirm that research approaches also need to include consideration of the impacts and contributions of humans on human, animal and environmental health.

Building on Craddock and Hinchliffe's (2015) argument, this chapter emphasizes the importance of a reflective stance in all stages of the research process. What do we mean by 'integration' and 'partnership', two key terms used in defining One Health approaches? Who integrates whom under what terms? What are the assumptions underlying the relationship between partners? Who are the experts, whose knowledge and practice counts, when, for whom and why? Improving health, solving health problems and responding to disease outbreaks and other types of ill health seem to be universal human goals. However, if we start to investigate how actors of diverse cultural, gender, social and economic backgrounds understand and judge what experts (e.g. those trained in biomedical sciences, clinical, environmental and veterinary sciences) conceptualize as health problems, emerging or resurgent diseases and proper interventions, we begin to realize that these are not just biological but also cultural phenomena – as already observed by Calvin W. Schwabe.

One Health itself can be analysed as a cultural phenomenon, shaped by social and political relationships. Looking back on its history, Cassidy (2017) sees One Health as a response mounted by specific scientists, clinicians and policy makers, working in specific institutional and organizational contexts, to problems that manifested themselves at particular times and in particular places. Cassidy comments: 'In contrast to advocates' claims, it is not a self-evidently beneficial phenomenon, nor the result of inevitable progress, but a contingent and context-bound activity that is actively and continually created through persuasive rhetoric and alliance-building' (Cassidy, 2017, p. 196). This becomes even clearer when social scientists trace how the One Health movement travels around the globe, for instance to African countries. Okello and colleagues (2014) have shown for Uganda, Nigeria and Tanzania, the 'goodwill' of practitioners and policy makers is there, but they face many challenges in planning, executing and budgeting for joint interventions. Inequities (in access, affordability, quality, health rights) may be embedded in policies developed for low-income and indigenous communities. Rock *et al.* (2017) in discussing rabies control programmes describes this as an 'entangled phenomenon' of animals, human injuries, public policies and rabies. These and other social science studies can contribute to gaining deeper insights into not just whether, but how, One Health as an approach for intervention and action may be achieved.

A better understanding of 'knowledge', 'attitude', 'behaviour' and 'practice' is key to advancing the One Health agenda, not just for studies on local actors who may be, for example, potentially at risk of being infected by parasites that are transmitted from animals to humans. Words like 'knowledge' are terms used in everyday language, but in social science research they must be conceptualized with reference to theory. As the prominent medical anthropologist Arthur Kleinman (2010) elaborated in a *Lancet* article, a foundational theory in the social sciences is known as 'the social construction of reality', introduced by Peter Berger and Thomas Luckmann in the 1960s. According to this theory, the real world not only has a material basis, 'it is also made over into socially and culturally legitimated ideas, practices, and things' (Kleinman 2010, p. 1518). As an example, he refers to the spread of the H1N1 influenza virus that was 'made over' by global actors into the socially threatening and culturally fearful 'swine flu' epidemic. But he also points out that global health problems and programmes can (and often do) take on culturally distinctive significance in different local settings. What may be considered as a highly threatening health risk by global health experts may be regarded as one among many other health challenges by national policy makers and regional or local practitioners, and may not be recognized as a 'real' phenomenon by people exposed to this risk. This often leads to tensions between global policies and local reality and poses a challenge to medical and public health practice. 'A corollary of the social construction of reality is', Kleinman (2010, p. 1518) concludes, 'that each local world—a neighbourhood, a village, a hospital, a network of practitioners/researchers—realizes values that amount to a local moral context that influences the behaviour of its members.'

Social constructivist theory, as proposed by Berger and Luckman (1966), refers to an epistemological position in which knowledge – and values – is regarded as constructed on the basis of experiences, in interaction with other social actors and broader cultural, economic and political contexts, and is often not articulated in words but in practice. In this understanding, knowledge is not a 'thing' that can be easily elicited, for instance in a survey with predefined questions such as a KAP study, outside the vital context of experience. What constitutes a problem and what is a proper response to this problem is seen through a social lens.

Social constructivist theory is one among several social science theories that foster a deeper understanding of common sense terms like knowledge, attitude, behaviour and practice. We introduce it here because it provides a foundation for designing and conducting reflective and participative social science research in One Health as the following two case studies will show. Case study 2 highlights the deliberate inclusion and role of social sciences from the beginning to the end of a pilot intervention. It emphasizes the importance of reflections by all disciplinarians upon their approaches, beliefs and potentially unconscious biases towards Western science paradigms. It also illustrates the valuable role of the social scientists 'contextualizing' decisions to ensure truly participatory knowledge development and design – from conceptualization to policy development.

Case study 2. One Health participatory surveillance and response from diverse Guatemalan perspectives. Contributed by Mónica Berger-González and Brigit Obrist.

Background

Guatemala, like many LMICs, is facing rapidly changing ecosystems that increase the vulnerability of populations where public health care and animal health-care services are poorly implemented, often devoid of cultural pertinence or a good understanding of rural communities' way of life. The One Health Poptún intervention project aimed to develop a transdisciplinary process (see also Berger-González *et al*., Chapter 6, this volume) in the subtropical lowlands of Petén, to develop a surveillance and response system for key zoonotic diseases. This is an ongoing proof of concept implementation research between the Swiss Tropical and Public Health Institute, University of Basel, Universidad del Valle de Guatemala, the Ministries of Health and Agriculture, animal production people, the private company Tigo Telecommications Co., the Maya Council of Elders and community development councils. The longer-term vision is to scale up improved interventions into the health system.

With a predominantly indigenous Maya Q'eqchi' and Mestizo population, this ethnolinguistically diverse area is characterized by medical pluralism, where modern Western approaches to health care offered in the public domain coexist with a predominant Maya medical tradition in a situation of exclusion and inequity. The challenge was to produce a sensitive surveillance system that could capture local understandings of 'disease' and respond in culturally appropriate ways deemed desirable by locals. This was only possible through using a strong anthropological approach that articulated a mutual learning process between epidemiologists, medical doctors, nurses, veterinary doctors, Maya traditional healers, local animal and human health authorities and service providers, and community leaders. The project adapted the Explanatory Model of Illness approach (Kleinman, 1978) to examine how each of these groups understand and judge the relations between human–animal interactions, health and illness.

The importance of acknowledging diversity: issues of representation and participation

The project aimed to address stakeholder's interests on an equal footing in order to increase legitimacy and buy-in of the design, and to facilitate overall implementation of the surveillance-response project. In a post-war setting plagued with mistrust and historical trauma (Chamarbagwala and Moran, 2011), this proved a hard concept to enact. Social scientists conducted contextual and historical research for the study area to understand emerging trends possibly precluding participation of expected groups. An intersectionality approach (McCall, 2005) identified the groups most vulnerable to be excluded or misrepresented within the project. Results showed a context of extreme power differentials triggered by specific

Case study 2. Continued.

conditions that were organized in categories (ethnolinguistic composition, gender, distance-access, literacy, multilinguistic capacity, socio-economic composition, racist attitudes-practices). These were used to redesign transdisciplinary workshops, which included exercises to address power disparities, value rather than fear diversity in representation, and induce reflexivity. Quotas for types of participants were created (i.e. Maya, female, rural, traditional healers) to promote agency of societal actors originally excluded from the project but who were identified locally as key to successful project implementation. Anthropologists also developed specific methods to curb ethnocentric behaviour of researchers that precluded them from understanding local views of the human–animal interface domain.

Approach to development of intervention

Pluri-epistemic systems: ethnography as a tool to uncover underlying models of 'zoonosis'

Beginning with the conception and design of the project, anthropologists, veterinarians and public health experts from Guatemala and Switzerland worked hand in hand as equal partners, defining an initial interdisciplinary transversal study. Each disciplinary group also conducted its own studies. Veterinarians and epidemiologists studied animal and human samples to determine zoonotic diseases, while anthropologists analysed local understandings of how human–animal interactions may affect health and illness. In regular meetings and workshops, the research team engaged in reflections about similarities and differences of explanatory models held by different categories of study participants (including the researchers). Ethnographic research on the mental models of the local population concerning disease transmission between animals, humans and the larger environment showed most Maya people drew on broader values of *Tzalajb'il* (harmony), *Nimb'el* (respect), *Sahil Wanq* (coexistence) and *Xbisbal li wan* (balance) to define an exchange of 'energies' between the species. A deep-seated notion of an assumed benevolence of nature precluded seeing pathogens of animal origin. This proved a key finding for the later co-design of education and communication strategies aimed at local communities. Apart from strictly Maya or strictly biomedical models of (zoonotic) disease transmission, the team found numerous hybrid models held by local health providers as well as by community members, influencing health-seeking pathways and treatment of patients. For example, Maya midwives that also served as 'health guardians' for the public health system, referred to energetic diseases such as '*hijillo*', a disease believed to be transmitted from a dog to a child via the dog's energy (non-material contact) but also from contact with afterbirth fluids. The midwives and health guardians explained that symptoms such as fever, diarrhoea, vomiting and lethargy in children would inevitably result in death. While noting that *hijillo* could be cured only through a Maya ceremony and medicinal plants, they also prescribed antibiotics in very small doses. These various models along the biomedical–Maya spectrum were analysed jointly by team members to understand the diversity of epistemic (knowledge) systems influencing health-seeking behaviour.

The emics of One Health surveillance

Social scientists employed the Bidirectional Emic-Etic framework (Berger-González *et al*., 2016) to elicit local (emic) categories of disease and terms for illness in animals and humans, which could be better suited for use in the surveillance system. Epidemiologists suggested unequivocal definitions for terms such as 'febrile syndrome' or 'acute respiratory syndrome', for which there was no direct Maya Q'eqchi' translation. Given that the project aimed to implement a community-based surveillance system relying on families' reports of perceived 'danger' signals, the team needed to understand how risk and illness were perceived locally. Working with Maya linguists and community representatives, local categories for syndromic surveillance that were more culturally sensitive were elicited, including them in the training protocol of the local nurses who had to document the human health cases occurring in studied households. For example, the desired term 'diarrhoeic syndrome' found several local terms in Spanish and over a dozen terms in Q'eqchi' (i.e. *Xha' chi sa'* – diarrhoea as water, *K'ik sa'* – diarrhoea as water with blood, *Sam ko't* – depositions with mucus, *Xah' chi kem* – soft but rapid depositions, etc.) that allowed the team to define a more precise and sensitive syndromic surveillance system for both animals and humans.

Boundary management: a case for mutual learning

Medical systems present particular idiosyncrasies that are deeply related to the way in which the social world is perceived and acted upon (Levin and Browner, 2005). In Guatemala, social divides often preclude the modern biomedical system and the Maya medical system from easily interacting in public spaces, creating boundaries that are often detrimental to patients and successful public health interventions. The project addressed this divide via joint diagnostic protocols

Case study 2. Continued.

that allowed the bridging between the two medical systems. To examine explanatory models of concrete episodes and their treatment in more detail, the study team organized joint visits of patients where a Maya *Ajkum* (traditional healer) and a biomedical doctor would jointly diagnose and discuss response avenues for human patients, or an *Ajkum* and veterinary doctor would do the same for animal patients. In a visit with a woman suspected to have leptospirosis, the medical doctor asked questions about risk exposure and unspecific symptoms such as fever and lethargy, and recommended laboratory tests to confirm aetiology. The Maya healer used an ancient technique called '*pulso*' to diagnose 'a disease similar to dengue but coming from a much older disease transmitted by a mammal, possibly a bat'. Most importantly, he suggested the patient had a precondition called '*susto*' (a well-known culture-bound syndrome relating to losing one's vital energy or spirit) that had weakened her 'blood' (immune system) and had made her susceptible to the disease. An example of boundary management in One Health is illustrated in our short video: https://youtu.be/lfVQnsqLbas (accessed 15 July 2019).

Results

Discussions on treatment avenues showed indigenous patients preferred responses that incorporated both biomedical and Maya treatments collaboratively, providing valuable insights into the role of cultural pertinence for increasing treatment adherence to previously unknown zoonotic diseases. In other words, this intercultural diagnostic study showed that incorporating traditional medical system approaches facilitated compliance with biomedical response protocols that were otherwise too novel and frightening for indigenous patients. In the above-mentioned case, the woman was treated in a hospital for leptospirosis and brucellosis after laboratory confirmation, but was previously treated for '*susto*' by the Maya *Ajkum*, having refused to go to the hospital without her spirit being called back first. For this approach to elicit respect and avoid promoting further divides, social scientists carefully designed and guided the exchanges to facilitate a process for mutual learning between the different kinds of health practitioners and research disciplines by attempting to understand each other's emic views on human–animal disease transmission. These diverse understandings and their implications were used to stimulate discussions across explanatory models within the research team and with transdisciplinary partners.

Outcome

The analysis of the 'pilot' intervention undertaken as a local proof of concept was presented in workshops fed into a larger 'scale-up' intervention design. These interdisciplinary workshops and conferences were aimed at promoting the One Health approach to community surveillance at a national level.

Case study 3 illustrates a grounded open-ended adaptive approach to local identification of problems by the community and local health workers, and a co-creation of knowledge and interventions. It illustrates the existence of differing world views on the problems identified and the need to approach health and well-being in a transdisciplinary manner, recognizing the interwoven concepts of human lives, animal lives and the environment affecting health.

Case study 3 also illustrates how the combined effects of environmental, human and animal behavioural changes create a cycle of changes in the health of each of these three domains.

Medical anthropology has placed limited focus on non-human species in understanding disease and health (Rock, 2016) and on environmental or ecological anthropology (Moran, 2008). There are some studies emerging on interspecies relations in social anthropology in general and especially in the sub-field of research in ecological and environmental anthropology. One example is Ruhlmann's work (2018) on highly contagious animal diseases and their spread to other animals and humans. This work explores the complex spaces of veterinary and human medical ethnographies of the herders, coexistence between and meaning of the relationships between humans and their animals, political economies, and veterinary public health practices. It is an example that can provide valuable insights for addressing serious infectious diseases that affect production animals, economic value, and transmission to humans. The 'reverse zoonosis' pathway, that is of animals being infected by humans is also under-addressed. Yet it could have major economic, animal (including wildlife) and human consequences (e.g. production pigs being infected by 'flu' from human carriers working in the industry, and the rarer and fascinating cases of elephant tuberculosis

Case study 3. Atoifi Health Research Group (AHRG) – how a One Health social science approach is being used in the remote Solomon Islands. Contributed by David MacLaren and Humpress Harrington, James Cook University and AHRG and Chief Esau Fo`ofafimae Kekuabata, AHRG and Kwainaa'isi Cultural Centre.

Background

AHRG is a group of health researchers, health service professionals and community members committed to investigating locally appropriate ways to improve health and well-being in remote locations across the South Pacific Nation of Solomon Islands. Solomon Islands has 600,000 people, who belong to 80 different indigenous language groups. The majority (85%) of the population live in rural/remote villages located on tribal/customary land and are sustained through the subsistence economy or via remittances from family members who work in urban areas. Villages are located across the rainforest mountains, fertile valleys, coastal beaches and coral atolls. AHRG does much of its work in the remote East Coast of the Island of Malaita. Although only 120 km long and 30 km wide, the island of Malaita has ten distinctly different language groups, each following their own cultural traditions on their distinct tribal/customary land.

The AHRG is committed to a learn-by-doing approach to research that centralizes capacity building to enable Solomon Islanders to incorporate diverse social, cultural, spiritual and geographic contexts. This approach has been successfully used for more than a decade to address several social and health problems. (For more details, resources and videos of the AHRG work, see https://www.atoifiresearch.org.sb/ (accessed 15 July 2019).) The AHRG is a transdisciplinary partnership between academic researchers, health service professionals and community leaders that jointly identify local health issues, jointly design locally appropriate studies, jointly record results and jointly inform locally appropriate action. A One Health social science approach characterizes the AHRG and enables a detailed and nuanced understanding of the human–animal–environment interface in specific locations. Because of the hyper-diversity that exists across humans, animals and environments in relatively small geographic locations, the group advocates two mantras: 'small is beautiful' and 'one village at a time'. Thus, the researcher-service provider–community leader network that makes up the AHRG combines skills and approaches to investigate human, animal and environmental issues concurrently or sequentially, and supports cross-village learning. The social sciences are purposely embedded into the design of health studies designed and conducted by the group. This deliberate approach allows for a nuanced practical and theoretical understanding of infectious and non-infectious diseases in their local contexts in order to design or influence the provision of health services to their communities. Use of social sciences allows for the deliberate investigation and incorporation of culture, gender, spirituality, economics, ecology, cosmology, politics, history and indigenous knowledge. Through these lenses, family and household structure, gender, land use, food production, domestic and wild animal ownership/usage, religious and philosophical worldviews, traditional and contemporary political organization, cultural communication, local and external economics, personal and collective hygiene and sanitation and gender roles are incorporated into health and well-being projects. It is our experience that these are all fundamental to subsequent human, animal or environmental action. Examples include the following.

Soil-transmitted helminths

Social science was embedded from the very beginning of our soil-transmitted helminth studies. How villages were engaged in the studies was part of their success. Village engagement included: (i) open community information sessions during church gatherings; (ii) social, cultural and gender considerations for human and animal faeces collection, testing, transport and disposal; (iii) feedback of results to villagers through village forums; and (iv) discussion of location and design of water and sanitation actions to reduce parasite transmission. Local actions to improve male and female toilets, including their design and location in villages, were informed by local cosmological designation of 'male' or 'female' appropriate locations (Harrington *et al*., 2015; Bradbury *et al*., 2017, 2018). For documentaries on how social science was purposely embedded in the design and conduct of the studies see: Parasites in Paradise: a Soil- transmitted Helminth Survey in Marovo (available at: https://youtu.be/ZRzg4C7Mmas) and Toilets and Taboos in the Tropics (available at: http://www.youtube.com/watch?v=FMtc3f6xESU) (both accessed 15 July 2019).

Traditional knowledge of medicinal plants

In the face of large-scale logging in many parts of Malaita, many of the communities involved in the project wanted to preserve areas of the rainforest as

Case study 3. Continued.

a 'living pharmacy' to sustain health and well-being for the humans, animals and environment. Social science was embedded throughout this project to document the taxonomy of rainforest plants used by local people for medicine and food. The project worked with local tribal groups in order to document local knowledge of medicinal rainforest plants and create a bilingual book (Kwaio language and English) and set of videos as a health education resource for the community and outsiders. The success of this project was dependent on intimate knowledge of the land ownership structures, local political leadership, gendered knowledge systems, access to remote parts of the rainforest and support for local archive systems at the Kwainaa'isi Cultural Centre. Subsequent action by the community saw the formation of conservation areas designated by local ancestral spiritual decrees that blocked commercial logging as a way to conserve plants and animals in these locations. The conservation areas are managed locally by tribal leaders on their own tribal land and act as an example of the One Health human–animal–environment interface (Esau and the Kwaio Medicinal Plants Project Team, 2015; Atoifi Health Research Group, 2018). Short videos from the medicinal plant project are available at: https://www.youtube.com/playlist?list=PL-m8H163i-wTAxHB7bg4JJTfZWImHyHLSj (accessed 9 June 2020).

Mental and spiritual health and well-being

Colonial history and politics are a constant reality in this ex-British colony. A colonial era massacre in East Malaita in the 1920s involving the Australian military had never been resolved. In 2018, a traditional reconciliation ceremony was facilitated between Australian researchers and local Kwaio tribal leaders to acknowledge the events of the past and plan for the future. Pigs and traditional shell money were exchanged in a sacred site near Kwainaa'isi Cultural Centre. This deeply cultural process required an intimate understanding of culture, gender, spirituality, cosmology, economics, ecology, politics, history and indigenous knowledge by all involved and informed by villagers. This holistic One Health approach with embedded social science methods was able to inform historic and contemporary health and well-being activities implemented at local level by health services in partnership with villagers across the human–animal–environment continuum (Flannery, 2019).

Health impacts of climate change

The AHRG also studies the health impacts of climate change. Villagers living on coral atolls or in low-lying villages experience periodic inundation and loss of productive land as sea levels continue to rise. This reduces arable land and impacts food production. In some villages, the surrounding mangroves are used as toilets. During normal tidal flows, human waste is washed out to sea, but during times of inundation, human waste is washed into areas inhabited by humans and animals. Sea level impacts mental health as villagers become increasingly anxious prior to the high tide season, when they know they will be inundated. This impacts both the living and the dead as burial grounds are inundated and eroded. Because people live on tribal land, most are unable to move and so other responses to sea level change are being considered by the communities rather than migration (Asugeni *et al*., 2017). See also Adapting to Sea level Rise: a Young Woman's Story, available at: https://youtu.be/VoDCtcIcAOs (accessed 15 July 2019).

Conclusion

The 'small is beautiful' and 'one village at a time' approach used by AHRG is a One Health social science means to understand the human–animal–environment interface in these remote locations in order to improve health and well-being and the related services in a scientifically sound and culturally respectful manner. It continues to be used by the AHRG locally as well as through their participatory approach to capacity development in other locations in Solomon Islands.

coming from humans) (Laine, 2018). The emerging field of multispecies ethnography provides an opportunity to reorientate social science approaches to better examine human–animal–environment entanglement and 'revisit theorizations' of central topics in medical anthropology' (Brown and Nading, 2019, p. 5; see also Kirksey and Heimreich, 2010).

Designing and Implementing One Health Approaches with Social Science Integration

There remain few descriptions of integrating social science in the planning, implementation, monitoring and evaluation of One Health interventions in the published literature, especially beyond pilot research projects. Case study 2 adds another valuable contribution to address this knowledge gap. In Chad, deliberative integration of social science research in the design phrase enabled the findings to be utilized to develop health-care programmes for nomadic pastoralists (Schelling and Zinsstag, 2015). In Fiji, social science was one of the disciplines engaged in the transdisciplinary process to develop the National One Health Control Programme (Reid and Kama, 2015). One of the barriers to integration remains lack of appreciation of the value that social science can add to the design and implementation of interventions, and their outcomes and impact. Beyond having baseline and endline KAP, there are few descriptions of a fully integrated transdisciplinary approach to a One Health problem. One example is in Nunavik, Canada where the Inuit people, anthropologists and veterinarians started working together to develop more culturally suitable and respectful dog management practices. The aim is for more effective implementation for rabies control and to address other common health issues (Levesque, 2018). Additional examples are included in Chapters 18–27, this volume.

It should be noted that there are also limited published quality evaluations of any One Health intervention around the issue of the integration of social science. However, a review of 'proof of concept for the One Health approach to emerging disease threats provides evidence that transdisciplinary integration among the sectors of human, animal, and environmental health is feasible' (Rabinowitz *et al*., 2013, p. 6).

Rwanda has developed a One Health strategic plan to 'streamline cross-sectoral and institutional interventions, minimize duplication of efforts, and maximize the use of public resources' (Nyatanyi *et al*., 2017, p. 3). Included in this plan is the promotion of interprofessional collaboration in research and innovation and its linkages to programme development and implementation. However, it is early days yet, and although they hope for a broad approach to problems like food security, antimicrobial resistance, animal and human infectious disease outbreaks, it will take time. Some newly announced projects, such as Operationalizing One Health Interventions in Tanzania (UK Research and Innovation, 2018), are designed to incorporate social science into the design, and may provide valuable insights to address this knowledge and practice gap. In Switzerland, One Health plans have been developed by the local government in some cantons to address some priority health issues of non-communicable diseases, mental health and health hazard surveillance (Meisser and Goldblum, 2015).

One way to increase appreciation of and integration of social science into One Health approaches is through engagement and dialogue across disciplines and professions. Rock *et al*. (2017) discussed how, in order to have rabies and dog bite research enhance policy alignment and task integration between animal control and public health services, they developed a forum to share the results of their research with animal control officers and public health officials in a variety of settings. Many anthropologists have advocated for 'greater social science involvement in One Health initiatives, seeing possibilities to attend to new dimensions of inequalities revealed at human–animal interfaces within enlarged understandings of pathology' (Craddock and Hinchliffe, 2015, p.1) and 'others have identified opportunities for "critical and constructive social science engagement with One Health"' (Brown and Nading, 2019, p. 9). (For further discussions see also Rock *et al*. (2009) and Dzingirai *et al*. (2017).) There is a need for better documentation of how social science has made changes to the effectiveness of joint and integrative identification of problems, design of interventions and their implementation, including their success in being relevant to, culturally appropriate for and meeting the requirements of those in greatest need.

Discussion

Discussing the added value of integrated approaches in One Health strikes at the core of complexity studies, where we acknowledge that the interconnectedness of the human–animal–environment interface requires a multiplicity of lenses to capture enough information to make syntheses typical of academic research a reasonable endeavour. Social scientists, trained to understand emic models of self and other, are well positioned to address the interpretative nature of paradigms shaping particular knowledge systems within the professions and disciplines (e.g. the diverse interpretations of veterinary doctors or epidemiologists as to what variables need to be addressed in One Health), facilitating intra-team dialogues to better represent the human–animal–environment subsystems.

Going beyond state-of-the art scientific production, One Health claims include the dimension of producing socially robust approaches contributing to public health. The role of social sciences then becomes evident as foundational for the co-production of interdisciplinary understandings of One Health by linking disciplinary experts in relevant approaches to particular complex health problems and various societal contexts. As the case studies show, a socially robust orientation requires contextualized thinking, an approach sensitive to cultural, historical and gender aspects shaping determinants of human, animal and environmental health. Additionally needed are mechanisms to see the linkages and feedback loops of human behaviour and observable disease, with the animal world and environments, and a capacity to address and integrate multiple ontologies and epistemologies of diverse stakeholders. The social sciences can provide evidence around power relationships, and the differential positions of various groups of people in social settings and economic markets, which support addressing the inequities often seen in accessing health interventions (Craddock and Hinchcliffe, 2015). Craddock and Hinchcliffe (2015, p. 2) note that social science brings to the One Health agenda an ability to 'foreground uneven geographies, uneven power relations, discrepant risks and variable access to resources'.

Social science also fosters participatory approaches that recognize multiple epistemologies and join academic disciplines, engaging partners, including communities, in mutual understanding of practices and explanatory models. It assists in examining the 'myriad configurations, textures and dynamics of human and non-human relations' (Craddock and Hinchcliffe, 2015, p. 3; see also Fuentes, 2010) and supports recognition of the voices, agency and expertise of the 'oft-forgotten' – communities, minorities and vulnerable populations. This was illustrated in Case study 1 for women food producers in Africa and Asia, in Case study 2 for indigenous populations in Guatemala and in Case study 3 for the Kwaio peoples of the Solomon Islands. This participatory transdisciplinary approach will undoubtedly yield robust interventions that are more effective in achieving desired outcomes and impacts and more likely to be sustainable.

However, as we have shown, social science interventions are not yet systematically used in One Health programme design and evaluation, which is often developed as research to address a problem with or without linkage to a service delivery. Lapinski *et al.* (2015, p. 52) note that 'there is a paucity of research regarding efficacious approaches'. This requires social science to be utilized in programme development. What should be done about this underutilization of social science approaches in One Health programmes and interventions?

There remain other questions about the level of integration of social science approaches and the insights they provide into One Health programmes and approaches, and especially, the territory beyond infectious diseases. These include the following.

- Are social scientists partnered with to conceptualize a programme, to value the unique insights provided in complex and adaptive systems?
- Are social scientists undertaking these studies in parallel to programme developers, where the value of integration is not yet fully appreciated?
- Are they only used to help access communities and populations, so that interventions are 'accepted' (tolerated) by the 'target populations'?
- Are well-trained social scientists being employed, or are social science methods being used by others without robustness, to try to improve acceptability of their programmes, or at least foster community engagement and health education? For example Keck (2019, p. 38), when reviewing social science engagement in programmes of zoonotic infection control, questioned whether the social scientists were being engaged to bring 'intellectual interest and ontological challenges of an anthropology of zoonosis beyond the regular calls for expertise on epidemiological contagion or on social participation'.
- Are we really seeing One Health social science or animal, human and environmental social sciences methods that are siloed? As demonstrated, if a social science approach is used, medical anthropology seems to be the dominant approach to develop a One Health understanding of human health problems, with little integration with environmental, ecological and non-human species anthropologies. However, emerging sub-disciplines like multispecies ethnographies are challenging this dominance, and platforms like the One Health–Social Science Initiative Hub may assist in crossing these 'boundaries'.

Conclusion

As outlined in this chapter, social science adds value in identification, design and implementation of One Health interventions. It has been used to provide insights into the importance of reflexive methodologies, how knowledge systems help shape the research and intervention outcomes, the ethnocentricity of etic explanatory models and the significance of emic views or multiple epistemologies, and how such understanding helps generate more robust data and mechanisms for implementation of these interventions.

The One Health approach enables a broad range of social science disciplines to come together to examine these issues, fostering theoretical and integrative innovations in understanding culture, economics, gender, ecology, behaviours, political contexts and indigenous knowledge.

There remains a need for social science to take a more active role in the design and conceptualization phase of programmes, and in helping multidisciplinary teams address potential design bias, inaccurate representation of various agencies, or cultural myopia. There is also a need to develop more robust approaches to evaluation of the success and sustainability of transdisciplinary approaches and the integration of social science into One Health programmes. In addition, the focus of the social sciences in One Health needs to be broadened to include tools, approaches and theories that truly embrace the human–animal–environment interface (Brown and Nading, 2019) and resilience strengthening (Obrist *et al*., 2010) and adaptations that occur within each of these and in the interfaces. Social science in One Health is applicable and adds value to understanding and meeting many of the grand challenges facing the planet, as delineated in the Sustainable Development Goals. There continues to be a need for publication and dissemination of successful models of social science integration in One Health approaches and the impact this integration brings to interventions, and a need for such approaches to be robustly evaluated and available beyond discipline-specific peer-reviewed publications.

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8 One Health Study Designs

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Introduction: What is a One Health Study?

Human and animal health epidemiological studies use field surveys or secondary data analyses. Data collection and data interpretation are traditionally done within animal and human health sectors and during different periods, or when an identical health topic is approached, which leads to unneeded duplication of field studies. Studies on zoonoses and foodborne pathogens are mainly led by veterinarians. A classical livestock sector approach to foodborne pathogens is risk assessment along the production and marketing chain. This allows identification of the point of greatest leverage of control measures. However, human incidences are not assessed. Human health hazards are identified, and impacts on human health are extrapolated from numbers. It is encouraging to see that risk assessors of foodborne diseases and antimicrobial resistances increasingly reach out to their colleagues in the public health sector and short cuts to risk identification and quantification can be achieved. New integrated disease surveillance systems are under evaluation (Stärk *et al*., 2015; Wendt *et al*., 2015; Hattendorf *et al*., 2017) (see also Aenishaenslin *et al*., Chapter 9, this volume).

From separate studies, it is difficult to draw coherent conclusions on linkages between human and animal health. Questions such as 'Which is the most important livestock species involved in brucellosis transmission to people in West Africa?' can hardly be answered. Results from other regions such as the Middle East, where people are mainly infected with *Brucella melitensis* from small ruminants, may not be valid. Epidemiological associations between positive human cases and positive livestock cases in different livestock species are best assessed in simultaneous studies of both people and animals with an emphasis on identifying the animal species acting as a reservoir for *Brucella* spp. Knowing the main source of human infection is important to achieve the greatest leverage in reduction of human infections.

A One Health study implies that data on human and animal health, possibly also on ecological indicators, are analysed in an integrated way and are interpreted together after transparent data and information sharing (Swiss Commission for Research Partnerships with Developing Countries, 2018). Sometimes these data are from different studies or data sources, but they should be comparable in terms of location, time, level of aggregation, details and quality, and a multidisciplinary team should publish the results together. A One Health study should lead to insights that would not be visible without intersectoral collaboration such as impacts of multi-host infections on humans, animal and ecosystem health and economics (Häsler *et al*., Chapter 10, this volume; Zinsstag *et al*., Chapter 31, this volume). Rabinowitz *et al*. (2013) defined a One Health approach similarly: 'Integrated approaches that consider human, animal, and environmental health components that can improve prediction and control of certain diseases'. This is not only true for infectious diseases, but also for non-communicable diseases and health-system strengthening. The aim is not necessarily improved human health or averted human burden of disease. Messenger *et al*. (2014) showed that an increasing number of reports indicate that humans are transmitting pathogens to animals. Recent examples include methicillin-resistant *Staphylococcus aureus*, influenza A virus, *Cryptosporidium parvum* and *Ascaris lumbricoides*. A One Health study would show bi- and multidirectional relations between human and animal health and their health in relation to the health

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of their ecosystem (Zinsstag, 2012). Thus the aim is ideally improved human, animal and ecosystem health (Allen-Scott *et al.*, 2015).

The most difficult step of a One Health study remains the initiation of a process that leads to change and health improvement. Solutions for successful control of neglected zoonoses may be outside the health sectors: for example, policies may need to be mainstreamed into poverty reduction strategies and continuous training to build health service skills and competences. Networking and regional approaches have been successfully used for zoonoses control (Parkes *et al.*, 2012). Avian influenza led to the establishment of highly recognized networks for exchange of information and lessons such as from the Asian Partnership for Emerging Infectious Diseases Research and the Mekong Basin Disease Surveillance (Grace *et al.*, 2011). For most zoonoses, one country alone can hardly implement successful control measures without the neighbouring countries doing likewise. Disease-control programmes designed in developed countries for industry-wide application cannot be transferred without appropriate adaptation to other settings (Randolph *et al.*, 2007). Many factors critical to successful disease control cannot be assessed quantitatively. The way forward is to enhance interdisciplinary cooperation between the social and health-related sciences (Whittaker *et al.*, Chapter 7, this volume). Note that the literature is richer on studies describing broader socio-cultural considerations for emerging rather than endemic zoonoses. These are, for example, human encroachment into forests with potential exposure to new pathogens, global travel and eating of bushmeat. While One Health recognizes the importance of understanding the social and cultural factors in disease transmission dynamics and the planning of control interventions, anthropological studies on zoonoses are sparse and limited (MacGregor and Waldman, 2017). Socio-cultural One Health surveys and the role of social sciences are described elsewhere in this book (Whittaker *et al.*, Chapter 7, this volume).

In this chapter, we focus on population-based quantitative One Health study designs with emphasis on planning of field studies. Such studies are central to the understanding of disease dynamics and for evidence-based evaluation of control measures. In addition, data for cost–benefit and cost-effectiveness calculations (Zinsstag *et al.*, 2007; Häsler *et al.*, Chapter 10, this volume) are hardly available at the central level alone and high-quality field data is needed. Therefore, laboratory-based studies using competencies from different sectors are not presented, although these largely contribute to, for example, improved and new vaccines against zoonoses and comparative pathology. We focus less on early detection of emerging diseases than on endemic zoonoses. The incidences of the latter are believed to be much higher, however, they are underreported due to low capacity to recognize and diagnose the causative agents of zoonoses. The simultaneous assessment of human and animal health outcomes should lead to a better understanding of the context and associated different disciplines (see Chapters 18–22 in Section 3(a), this volume).

A key discipline in One Health field studies is epidemiology, the study of health and disease in populations, or, according to another broad description of the discipline that only emerged in the 19th century, the study of the frequency, distribution and determinants of health and disease in populations. Epidemiology derives from the Greek language and literally means 'the study of what is upon the people'; 'demos' meaning 'people, district' (Omran, 1971). This may suggest that epidemiology applies only to human populations. Most veterinary epidemiologists believe, however, that it is pointless to use different terms such as epizootiology, epizootic or enzootic when referring to a disease in an animal population. The words 'epidemiology', 'epidemic' and 'endemic' should be used to describe disease occurrence in all host species. Epidemiology has also been applied to studies of plant populations (Bartlett and Judge, 1997; Nutter, 1999). Common in epidemiology is that a health-related question leads to a hypothesis and defines an objective, which leads to the appropriate study design to use.

We first provide a few selected examples on joint surveys, then on practical information for planning a field study design, and conclude on the advantages of One Health study designs. We also mention possible constraints for their implementation given that there are only a few One Health studies to date. For the examples, the main epidemiological considerations and the results that could not be achieved with single sector approaches are highlighted.

Examples of One Health Surveys

Joint human and animal health surveys are either done during the same period or in the same geographical area and at different levels of aggregation. Levels of aggregation are from individual (e.g. an owner–pet relation), household and village levels, and also communities and their animals, districts, provinces or countries.

Simultaneous human and animal health assessment

A simultaneous assessment of livestock milk and human sera vitamin levels, combined with a 24 h nutrition recall study, showed that milk was the most important source of vitamin A for pastoralists, but 17% of tested women were severely retinol deficient. Therefore, consumption of more vegetables and fruits needs to be promoted (Zinsstag *et al*., 2002). The latter survey could show the linkages between livestock and human nutrition, but was only done in one community. A comparison community of the same region in the survey would have better allowed conclusions on specificities and generalities of the findings.

A mixed team composed of medical and veterinary staff assessed during repeated cross-sectional surveys health and health-related issues of mobile pastoralists and their livestock using standardized clinical examination forms and questionnaires. The main diseases and conditions found among mobile pastoralists did not differ substantially from morbidity typical for the Sahelian zone, such as respiratory diseases, malaria and diarrhoea. Despite frequent diarrhoea and fevers, respiratory infections including lower tract infections in children and tuberculosis (TB) in adults, and malaria, had more impact on individual and community health than food poisoning and zoonotic diseases such as brucellosis. Therefore, a programme on control of zoonoses should not ignore other prevailing health problems of the communities. This simultaneous health assessment also showed that there was no fully immunized pastoralist child in the entire study population. In contrast, livestock had been vaccinated by veterinarians visiting the pastoralist camps during compulsory vaccination campaigns (Schelling *et al*., 2005). Based on this finding and in agreement with the communities and the Chadian national and local authorities, joint human and animal vaccination services were conducted and evaluated (Schelling *et al*., 2007).

Health impact assessments of industrial development projects could be extended to simultaneously assess livestock health, if veterinarians were also involved. Projects such as construction of dams and mining can adversely affect the health of the livestock kept by the surveyed households and have implications on their livelihoods and income. Hence health impact assessment could be extended to One Health Impact Assessment (OHIA) (Zinsstag *et al*., 2017).

Field surveys on zoonoses

Simultaneous assessment of zoonotic incidences and prevalences in animals and people at the same levels and same quality, for example regarding selection, helps to establish epidemiologic links. In Chad, human Q-fever seropositivity was associated with keeping of camels but not of cattle (Schelling *et al*., 2003); in Kyrgyzstan and Egypt human brucellosis seroprevalences were most closely related to keeping of sheep (El Sherbini *et al*., 2007; Bonfoh *et al*., 2012), and thus small ruminants cannot be excluded in a control programme. In Togo, human seropositivity was astonishingly low (below 1%), although cattle seropositivity was high (9% in village and 7% in transhumant cattle) (Dean *et al*., 2013). The isolated *Brucella abortus* strains from cattle harboured a large deletion in a gene (*bruAb2_0168*) encoding for a putative autotransporter. This gene is of particular interest because it is used as a target for PCR in identification of the species *B. abortus* and it encodes for a putative autotransporter which might be involved in virulence and/or host predilection (Dean *et al*., 2014).

In Ethiopia, *Mycobacterium bovis* in human TB infection is very low (four *M. bovis* isolates compared with 1000 *M. tuberculosis* isolates from clinical suspects of pulmonary and extra-pulmonary TB) (Firdessa *et al*., 2013). Interestingly, *M. tuberculosis* was isolated from cattle and one camel (Gumi *et al*., 2012). The latter study was a combined field, slaughterhouse and hospital study with data collection during the same period (Tschopp and Yahyaoui, Chapter 22, this volume).

The Health for Animals and Livelihood Improvement (HALI) project was initiated to test the feasibility of a One Health approach to find creative solutions to health problems in communities living in the water-limited Ruaha ecosystem of Tanzania. Simultaneous investigations of medical, ecological, socio-economic and policy issues driving the ecosystem were implemented. Based on input from local stakeholders, waterborne diarrhoeal diseases and cattle diseases were also assessed to identify geographic areas with varying water availability, where risk of transmission may be highest (Mazet *et al*., 2009). The researchers could show with the example of bovine TB that there was livestock–wildlife pathogen transmission in the Ruaha ecosystem (Clifford *et al.*, 2013).

Foodborne and waterborne zoonoses

Control of foodborne and waterborne infections requires input from public health, environmental health and veterinary public health practitioners as well as regulatory authorities responsible for safe food and water. They also require a deep understanding of how social, economic, environmental and cultural factors interact with dynamics of disease transmission and the acceptability of control measures (VSF Canada, 2010).

The Caribbean Eco-Health Program (CEHP) has supported interdisciplinary training, particularly of human and environmental health agents and assisted to identify regional knowledge gaps in environmental health threats such as pesticide residues, which were important to users and policy makers. The Atlantis Mobile Laboratory could move throughout the Caribbean respond to calls for specific research concerns and capacity-building opportunities (Forde *et al.*, 2011; Oura *et al.*, 2017) (see also Oura *et al.*, Chapter 28, this volume).

Total bacteria, *Streptococcus*/*Enterococcus*, yeast and mould, Enterobacteriaceae and *Staphylococcus* counts all increased along the chain from milk at milking to marketed milk in Kenya, indicating a human health hazard according to Kenyan quality standards. To test this, an unmatched nested case-control study – constructed from a cross-sectional survey – confirmed that gastrointestinal illness was significantly associated with consumption of certain vegetables and camel milk (Kaindi *et al.*, 2012). This study led to revitalizing past efforts enabling milk collectors to use containers that can be easily washed with water and soap (Bonfoh *et al.*, 2003). High levels of pathogens and other hazards in milk and milk products are reported from both the formal and the informal dairy sectors. The role of food safety in dairy policy potentially constrains the shift of policy to more pro-poor policies because informal markets are a priori excluded (Roesel and Grace, 2014).

Surveys of antimicrobial resistance

Pets are often companions used for psychological support in the therapy of nursing home residents but have also been described as reservoirs for antibiotic-resistant bacteria. To investigate the role of healthy pets as reservoirs of multidrug-resistant staphylococci or extended spectrum beta-lactamase (ESBL)-producing Enterbacteriaceae, several studies assessed these with the same approach in both people and pets in nursing homes and the general population (reviewed in Messenger *et al.*, 2014). Although identical genomic patterns from people and from animals have been found, the direction of transmission often remains unclear (Gandolfi-Decristophoris *et al.*, 2012). The same issues arose, for example, in TB. Cattle were infected with *M. tuberculosis* and could have acquired infection from people or from other cattle (Gumi *et al.*, 2012). It is likely the question on 'who infects whom' is not necessarily the primary question, since people and animals share the same ecosystem and evolve together, but rather which control measure has highest leverage in both people and animals (Tschopp and Yahyaoui, Chapter 22, this volume). Antimicrobial surveillance systems are discussed by Aenishaenslin *et al.* (Chapter 9, this volume) and Szelecsenyi *et al.* (Chapter 18, this volume).

Joint disease surveillance systems and use of routine data

In the Q-fever outbreak in the Netherlands (2007–2010), there were 4000 confirmed human Q-fever cases with 11 deaths and huge economic losses among dairy goat herds including slaughter of 40,000 pregnant goats (Enserink, 2010). Could the outbreak have been controlled earlier if the health and veterinary sectors had exchanged data and communicated at an earlier stage? Most abnormal disease events are seen rather late in the human health and veterinary sectors, despite the fact that early detection is a core objective of surveillance systems (Aenishaenslin *et al.*, Chapter 9, this volume). The cohort study set up in the Netherlands between 2007 and 2011 (van Loenhout *et al.*, 2012) included only people. A parallel cohort in goats may have led to additional links seen between events in people and goats.

Surveillance and monitoring efforts are major components and central to disease prevention and control programmes. Joint human and animal surveillance networks could be more effective in terms of earlier detection and have lower fixed costs compared to surveillance without intersectoral collaboration active surveys (Hattendorf *et al.*, 2017).

Currently such surveillance systems are being tested and are described in more detail by Aenishaenslin *et al.* (Chapter 9, this volume). Although they have been set up more recently, the added value in terms of increased surveillance system performance, economic benefits or improved data quality has been repeatedly demonstrated (Häsler *et al.*, 2014). Wendt *et al.* (2015) have reviewed systems and found that the majority of the 27 identified human and animal surveillance systems worldwide were established for the purpose of early detection and tend to focus predominantly on emerging pandemic threats. Most systems use distinct data sources, secondary data and different methods, and frameworks on the integration of disparate and secondary data are of great interest. Information integration is possible to achieve even though data have been collected in different surroundings and often for different purposes and thus differ in content, quality and terminology and are stored in different locations or formats. However, transforming and cleaning procedures have to be applied, and this requires time and effort when the different data sources have not been standardized or prepared for an easy linkage. Above all, cross-sectoral structures, trust and good communication networks are required (Wendt *et al.*, 2015).

Regional and national intersectoral data exchange cannot be expected to work if there are no collaborations at all levels of data reporting, at least to briefly cross-check reports. There is a need for consistent, reliable data at a national level, over a longer term, but also in the shorter term the need for reliable data to demonstrate the neglected status of the diseases. The lack of diagnostic facilities and regional reference laboratories for diagnosis of zoonoses in many parts of the world is a constraint to this, since most current joint surveillance systems rely on routine data from diagnostic laboratories (WHO/Department of Control of Neglected Tropical Diseases, 2009). In future, more alternative surveillance systems will be evaluated – such as syndromic surveillance, participatory epidemiology, risk-based joint surveillance systems, use of big data and emerging genetic data (Hattendorf *et al.*, 2017; Beard and Scotch, 2019). However, these systems still need to show that they can be effective in detection of abnormal events and that maintenance is not too costly. Also, to achieve added value of integrated surveillance systems requires shared objectives and strategies for institutional integration at the appropriate level (Mariner *et al.*, 2011).

Use of modern mobile technology for near real-time reporting will be used more frequently in future, for One Health and other surveillance systems (Thumbi *et al.*, 2019). But no near real-time reporting system should be established without providing possibility for responding to reported events. The lack of response capacity has stopped several surveillance systems in the past, because reporting ceased when the communities did not see any result to their reporting efforts (Karimuribo *et al.*, 2012). Also, monitoring can include other parameters than disease frequency or antimicrobial resistance. Stakeholders in zoonoses control and response capacity of the health and veterinary sectors can and should be monitored. For Rift Valley fever (RVF) in Kenya, a stakeholder analysis showed that the 28 relevant agencies in prevention/control of RVF go beyond the line of the livestock and public health sectors (Kimani *et al.*, 2016). A survey just after the RVF outbreak in 2006/2007 showed that the veterinary sector was understaffed to respond adequately to such an epidemic. The public health sector could deploy five times more staff than the veterinary sector, although the latter had more tasks during the outbreak situation (Schelling and Kimani, 2007).

Routine data is often compared with survey data to estimate under-reporting. For example, Cleaveland *et al.* (2002) found that active detection of human rabies deaths is difficult due to low incidence and the need to set up specific detection studies such as collection of verbal autopsy data from household surveys. Passive surveillance may be insufficient, leading to vast under-reporting of human rabies cases. However, animal bites can be surveyed given their rather high incidence and the likelihood of victims to seek professional care. Cleaveland *et al.* (2002) used a probability decision tree to estimate human mortality from information provided by animal bite victims. After validation with field studies, the authors estimated that in rural Tanzania the true incidence of human rabies was 10–100 times higher than the officially reported human rabies incidence. Rabies surveillance is further discussed by Léchenne *et al.* (Chapter 19, this volume).

Good routine data can be used for mathematical models (Chitnis *et al.*, Chapter 12, this volume) – for example avian influenza. A mathematical model of avian influenza transmission between wild birds and domestic poultry was used to provide proof of concept for a proposed integrated intervention involving human, animal and environmental health to interrupt such transmission (Guan *et al*., 2007). However, modelling of prediction is only possible where suitable primary (field-based) data are available. No model can improve data of doubtful quality.

Practical Considerations for One Health Studies

Study types in public health and veterinary epidemiology

Epidemiological research can be broadly classified into field-based and hospital-based studies. In veterinary epidemiology, studies at veterinary clinics are less common than in public health at health centres, and the main categories are field-based and abattoir/slaughterhouse-based studies. Obviously, field-based studies represent the general population much better than studies conducted in slaughterhouses, since the age distribution of the animals is different. Reviews found significantly higher prevalences in slaughterhouses compared with field-based surveys (Agrawal, 2012). In some settings, animal producers preferentially send older, unproductive or infertile cattle for slaughter, which increases the chance of detecting more chronic infections than in the general population. Conversely, farmers may prefer home slaughter if they fear condemnation of carcasses at abattoirs. Another constraint is the limited amount of additional information on the animals. Animal identification and tracking systems of animals from the abattoir back to the herd of origin hardly exist in low-income countries. Since intermediary traders are common in many parts of the world, information about origin, herd size or farming system is missing. On the other hand, field-based studies are much more resource intensive in terms of costs, time and administration. Besides more time and necessity for transportation, they also require higher logistical skills such as storage of samples until processing in laboratories.

Besides the study population, the study design is strongly linked to the associated level of evidence. For example, cross-sectional studies have a high risk of bias, which raises questions about the validity of the findings. A systematic review of high-quality studies is considered to have a high level of evidence. In 1972, Archie Cochrane highlighted the lack of reliable reviews of available evidence and established the concept of evidence-based medicine. It was soon recognized that there was also a need to develop systematic approaches to assess the study quality in other health sectors. Consequently, evidence-based veterinary medicine and evidence-based public health evolved. Unfortunately, until today few attempts have been made to adapt the evidence-based concept into the One Health context. However, numerous tools and checklists for assessing study quality are available, and the main aspects apply also to One Health studies (Rüegg *et al*., 2018). The main constraints that prevent a causal interpretation are bias, confounding and chance. One of the seminal papers on this subject was by Sir Austin Bradford Hill (Hill, 1965). The highest level of evidence is provided by experiments (i.e. cluster randomized controlled clinical trials). However, such trials are often not feasible for ethical, operational or financial reasons. Properly designed large cohort studies are usually graded as high quality. It is noteworthy that not only the level of evidence defines the most suitable study design, but also disease and exposure characteristics. For example, cohort studies are inappropriate if the outcome of interest is rare.

Sampling and sampling frame

In particular, inexperienced researchers commonly underestimate the complexity of planning and conducting sampling in resource-limited settings. However, an improperly drawn and not representative sample might introduce serious bias, which can easily double or halve the observed effective size. Unfortunately, only when controversial publications are published will the importance of proper sampling attract more attention (e.g. Burnham *et al*., 2006, which led to numerous discussions on 'main street bias' and showed the difficulties associated with proper sampling in urban settings). Next to careful sampling, a detailed description of the sampling approach used is mandatory. There are too many publications with an incomplete description of the sampling procedure. Likewise, research on sampling approaches and theory has been neglected by the scientific communities in both human health and veterinary epidemiology. There are only a few studies investigating appropriateness or bias associated with common but non-random sampling techniques such as 'spin the bottle' (i.e. spinning a bottle on the ground to select a direction). The potential of an unbiased-as-possible sampling using modern techniques such as geographic information system (GIS) and satellite images also remains underexploited.

Most statistical techniques require the theoretical assumption of a simple random sample (i.e. each individual from the population has the same probability to be selected and enrolled in the study). The sampling frame is a list of all members – or as complete as possible – from the population. Individuals are randomly drawn from the sampling frame, and all individuals have the same chance to be enrolled in the study. Where no complete registries of humans or animals exist, as is the case in most studies, a multi-stage cluster sampling is commonly used. In a first stage, clusters (i.e. administrative units such as villages or neighbourhoods) are randomly selected. If a nationwide study is done, selection may start at a higher level, such as provinces. Afterwards households or animal-keeping households are randomly selected within each cluster. In a final step, either all animals or a random subset of animals is selected. Cluster sampling is the natural sampling design in veterinary epidemiology, since livestock populations are typically clustered into herds or flocks. Surprisingly, cluster sampling is often confused with stratified sampling. Cluster sampling requires a higher sample size, which is not the case for stratified sampling, compared with simple random sampling. The differences are explained in Box 8.1.

Random selection of clusters

In contrast to lists of individuals, a sampling frame at cluster level (e.g. a list of all villages in a certain district) is usually available or can be established. There are two main approaches to select the clusters: (i) simple random sampling; or (ii) if the number of individuals within each cluster is known,

Box 8.1. Stratified random sampling versus cluster sampling.

In **stratified random sampling**, the individuals of the target population are first divided into subgroups called strata. Each individual belongs to one stratum. Then a random sample is drawn from each stratum (e.g. 10% of the population). This approach is advantageous if subpopulations vary greatly and the estimates in each subgroup or the differences between subgroups are of particular interest. **Cluster sampling** is an approach in which clusters of individuals rather than individuals are randomly selected. Like stratified random sampling, the population is divided into separate groups such that each individual belongs to exactly one cluster. Clusters are usually defined by geographic boundaries or administrative units, while strata can be defined as age groups, sex, etc., as shown in Fig. 8.1. Natural clusters are herds and households or villages. Depending on the research question, the cluster can be selected via simple random sampling or with a probability proportional to their size. Within each selected cluster, all individuals or a random subsample will be sampled. Cluster sampling requires rather sophisticated analytical methods and a larger sample size.

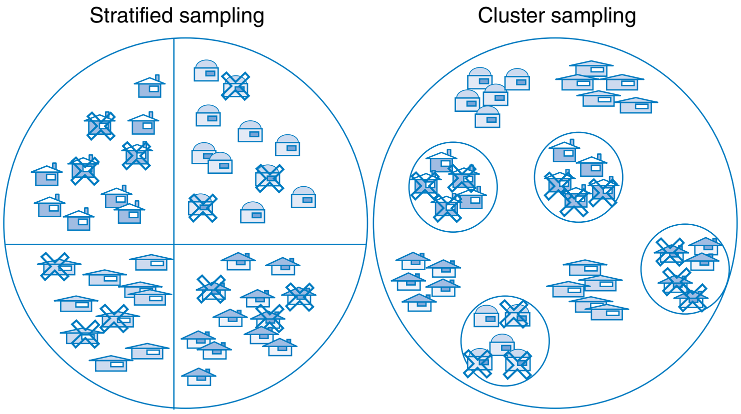

Fig. 8.1. Stratified random sampling versus cluster sampling.

sampling with probability proportional to size (PPS). For the former approach, the probability of individuals to be selected is higher in smaller clusters. Almost all statistical software packages are able to perform a weighted sampling. If there is no software available, the method can also be applied without computer assistance as described in Box 8.2. The main advantage of sampling proportional to size is that each individual in the population has the same probability of being selected. Since the risk of infectious diseases is usually density dependent, this approach provides an unbiased prevalence estimate.

A challenge in a One Health study is that humans and animals are investigated simultaneously. One needs to consider that selection probabilities can only be assigned to one population, thus either to the number of humans of interest or animals at the same time. One could argue for selecting the main presumptive reservoir host as the sampling frame. During data analysis, sampling weights can be used to produce representative estimates.

If a list of villages or neighbourhoods cannot be established – for example, slums are challenging in this context because they are very dynamic – alternative

Box 8.2. Sampling examples.

Example A: A simple method for sampling proportional to size as described by Bennett *et al*. (1991).

- Step 1. Randomly order the clusters in your study area;
- Step 2. Calculate the cumulative population numbers (e.g. 6700);
- Step 3. Select a random starting point: a random number between 1 and the total population size. In our example, e.g. 1814;
- Step 4. Calculate the sampling interval as number of clusters to be selected (e.g. 3) divided by the total population. In our example, 6700/3 = 2233; and
- Step 5. Select the clusters with the cumulative population number higher than the starting point, then add the next sampling interval.

Example B: It is sometimes ignored that the population size of the biggest cluster must be smaller than the sampling interval. If one cluster is larger than the sampling interval – as is the case in Example B – there is no valid sampling plan for equal individual selection probability; unless the research question and the study design allow that clusters can be selected more than once (sampling with replacement), which is commonly done in child vaccination coverage surveys. Different statistical software packages will handle this problem in different ways. The software environment R (base) will sample sequentially, which will not result in a sampling proportional to size. SAS (proc surveyselect) will return an error if a unit is too large. Stata does not have an inbuilt command to sample proportional to size. The user written command 'gsample' will stop with an error message.

Examples A and B are shown in Table 8.1.

Table 8.1. Examples A and B of sampling proportional to size, as described in the text, with ten clusters of different population sizes.[a]

	Example A				Example B			
Community	Population	Cumulative population	Selection probability of cluster	Start + sampling interval	Population	Cumulative population	Selection probability of cluster	Start + sampling interval
1	1000	1000	0.45		1000	1000	?	
2	400	1400	0.18		400	1400	?	
3	200	1600	0.09		200	1600	?	
4	**300**	**1900**	**0.13**	**1814**	**300**	**1900**	**?**	**1814**
5	1200	3100	0.54		1200	3100	?	
6	**1000**	**4100**	**0.45**	**4047**	300	3400	?	
7	1600	5700	0.72		*2300*	*5700*	*1*	*4047*
8	200	5900	0.09		200	5900	?	
9	350	6250	0.16		350	6250	?	
10	**450**	**6700**	0.20	**6280**	**450**	**6700**	?	**6280**

[a]Values in bold are selected clusters; values in bold italic indicate the cluster that has a size greater than the sampling interval.

approaches have to be applied. But the approach needs to be selected carefully, given that virtually all are subject to selection bias. One methodology that is assumed to be tolerably unbiased is the random generation of geo-coordinates within the study area using GIS or alternative software and selection of households or community closest to the generated point. However, bias may be introduced because households in sparsely populated areas have a higher probability to be selected compared with households from densely populated areas.

As for humans and animals, cluster-level inclusion and exclusion criteria must be clearly stated in the study protocol (e.g. villages must be accessible by car during the rainy season or must have at least one cattle-keeping household).

Sampling of humans within villages or communities

By far the most commonly used approach in selection of people in a rural community is via random selection of eligible households, but this approach requires a list of all households as the sampling frame. Such a list can usually be compiled by consulting the village head, who needs to be informed about the research activities anyway. To draw a map or to use a satellite image might be worth considering in longitudinal studies. Which households are eligible (e.g. only animal-keeping households or all households) depends on the disease, the cultural setting and the research question. When the priority is to cover as many villages as possible (e.g. for estimation of vaccination coverage) alternative procedures such as segmentation techniques and random transects (spin the bottle) are commonly applied, but especially the latter approach is more prone to bias.

After random selection of households, the next step is to sample persons living within the households. For certain research questions, only people with intense animal contacts may be of interest, but for a detailed understanding of the epidemiology and transmission pathways all family members are often considered eligible, although for ethical and practical reasons sometimes children or young children are excluded. In the ideal case, all family members are enrolled. But if the diagnostic procedures are time consuming or costly, it may be better to sample only some household members to ensure that the number of households will not be compromised. If only a single or few household members are selected, it is important to be aware of the 'household size bias'. Since all households have the same probability to be selected and a single person per household is randomly chosen, individuals in small households have a higher selection probability compared with households with many family members. Since household size is associated with the age structure – and many diseases have age-dependent distribution – the bias might be substantial.

Random selection of animals

Informed consent is sought before the sampling from all animal owners (see 'Ethical considerations in One Health studies' below). The investigator must be in charge of the random selection of animals. Animal owners are inclined to catch less healthy animals hoping that the investigating veterinarian would provide a treatment, and thus one should make sure that owners influence the selection as little as possible. If the owner has a complete list of all eligible animals, a simple random selection can be drawn. However, the most common sampling method is that livestock owners are asked to drive the animals into an enclosure or pen. The total number of the herd (e.g. 100 sheep) is divided by the sample size (e.g. 10), which gives the sampling interval (in our case 10). Every tenth sheep coming out of the pen is then sampled, whereby the first sheep is selected with a random number from 1 to the sampling interval.

Herd-level prevalence

For many diseases, not only the animal-level prevalence, but also the herd-prevalence is of interest. When all animals of the herd are sampled and a perfect diagnostic test is applied, no bias derives from the calculation of the herd-level prevalence. It becomes more complicated if the estimate needs to be corrected for imperfect test sensitivity and specificity and when only a small fraction of all animals is sampled. If animals are randomly chosen from each herd, the animal-level prevalence estimate will be unbiased, but this is not true for the herd-level prevalence. Formulae are available to calculate the corresponding herd-level prevalence (Faes *et al*., 2011).

Statistical analysis

Since cluster sampling is a study design feature and the outcome of interest is likely to be correlated within clusters, the statistical analysis has to take this into account. A comprehensive introduction goes beyond the scope of this chapter. We present some key aspects, which should be considered in the analysis. Theoretically, modern statistical software is in most cases able to handle several levels of clustering (e.g. animals within herds, herds within villages, villages within administrative units). However, in practice, often only one level of clustering is considered in the analysis. The main question in this context is: which is the ecological unit? If all animals within a certain village are free roaming and mixing at water points and during grazing, all animals from this village should be considered as one herd. If animals are held in fenced and dispersed pastures, the ecological unit is more likely the individual herd. An increasingly popular statistical method that accounts for the cluster-level sampling is the generalized linear mixed model (also known as generalized linear random effect model). This method also handles multi-stage cluster sampling. The disadvantage of this method is that it relies on strong assumptions, which usually cannot be verified. In particular, if there are many clusters with zero prevalence, the assumptions are likely to be violated. Alternatively, generalized estimating equation models (GEE) can be used. They are relatively easy to apply, but result in too narrow confidence intervals if the number of clusters is small (e.g. less than 30). In addition it is not possible to estimate the intra-cluster correlation coefficient (see 'Sample size considerations' below), and the interpretation is slightly different.

The combined analysis of human and animal data is challenging, since a certain person can only be linked to a certain animal under certain conditions. A joint analysis usually requires some level of aggregation or abstraction. However, for many research questions like evaluating the impact of an intervention simultaneously on humans and animals, the joint statistical analysis is less important than the joint presentation and interpretation of the results.

Sample size considerations

The sample size determination in cluster sampling is more sophisticated, since individuals within the same cluster have more in common than individuals from different clusters. Most infectious diseases require some kind of contact to spread, which is more likely if the hosts live in close proximity. Individuals within the same cluster may also be more similar with respect to environmental exposure, nutrition, cultural behaviour or genetic factors. This similarity is expressed by the intra-cluster correlation coefficient (ρ). Together, ρ and the average cluster size (b) can be used to calculate the design effect, which can be interpreted as a correction factor. The sample size calculated for simple random sampling is multiplied by the design effect (DE) to get the final sample size (Bennett *et al.*, 1991).

$$DE = 1 + (b - 1)\rho \qquad (8.1)$$

The value for ρ is usually unknown at the planning stage and difficult to predict. If no information from previous comparable studies in similar settings is available, ρ is usually set to 0.2. This value is chosen because it has been shown that ρ seldom exceeds 0.3 and is often below 0.2. Unless the number of individuals sampled is low, increasing the number of clusters will usually have a stronger effect on statistical power than increasing the number of individuals per cluster. It rarely makes sense to sample more than 30–50 individuals per cluster. Still, practical considerations should be taken into account. Where the distance between clusters is high, the number of individuals per cluster should be chosen so that the data collection can be completed in 1 or 2 full days. Finally, non-consent and, in longitudinal studies, loss to follow-up should be considered when determining the final sample size.

Ethical considerations in One Health studies

The common goal of veterinarians and physicians is to promote the health and well-being of their patients and to provide treatment where possible. There is overlap between the two sectors regarding individual versus community ethics such as cost containment, best use of resources (priority to most cost-beneficial and cost-effective approaches), herd immunity, sanitation and high-risk groups. Public health ethics has a broad scope that includes ethical and social issues arising in health promotion and disease prevention, epidemiologic research and public health practice (Coughlin, 2006). Ethical concerns in public health often relate to the dual obligations of public health professionals to acquire and apply scientific knowledge aimed at restoring and protecting the public's health while respecting individual autonomy. In veterinary medicine, the client (normally the owner of the animal) making the choice for treatment is not the patient. Nevertheless, there is a duty to communicate and disclose risks as in human medicine (Johnston, 2013). Epidemics affect not only farmers, but also the entire agricultural sector and even the national economy. Van Vlissingen (2001) published a list summarizing factors that play a role in the ethical evaluation of policies and actions on suspected cases of animal diseases. The list includes aspects of animals' interests, owners' interests, veterinarians' interests, interests of an animal population, public health interests and economic interests (see also Zinsstag *et al*., Chapter 2, this volume; and Wettlaufer *et al*., Chapter 11, this volume).

Any survey raises ethical considerations, which is also true for surveys on zoonoses without sampling or testing of people. Informed consent is needed from all interviewees. Participants have the right to know the results of the testing of their animals, since a positive result can present a health risk for themselves, their families and the consumers of their livestock products. A study on zoonoses requires close collaboration with governmental bodies. For example, it is unacceptable that the government would slaughter animals (without compensation) that test positive for brucellosis in the framework of a survey. Collaboration with authorities can also better ensure that the results are used to identify interventions that are fully carried by the communities. Appropriate protective measures must be promoted and their application facilitated by the project.

Advantages of and Possible Barriers to One Health Studies

The pressure to publish in high impact journals – the highest impact of which are disciplinary journals – forces researchers to split their findings and publish them according to the disciplinary strengths. Interdisciplinary/intersectoral efforts can get lost in this publication context. It is currently easier than in the past to publish interdisciplinary findings. But in one interdisciplinary manuscript, the disciplinary rigour of respective disciplines can only be sketchily presented, which, in turn, often does not satisfy reviewers of a given disciplinary background. Also, interdisciplinary journals may not reach the primary target audience. For example, a veterinarian more likely consults veterinary journals and not, for example, an ecohealth journal, despite the fact that this may have articles relevant to his/her work.

Most One Health studies are driven by veterinarians. Historically, the veterinary medical profession has held a focus on protecting and improving animal and human health. Unlike their contemporary human medicine counterparts, veterinarians must have multiple species knowledge (Kahn *et al*., 2007). Doctors are rather narrowly trained to do clinical work, and less so to consider interactions with the closer and broader environment. In this chapter we have presented only a few examples of projects considering ecosystem factors, although there should be a greater incorporation of environmental and ecosystem factors into disease assessments and interventions (Rabinowitz *et al*., 2013). An evaluation of the social-ecological systemic impacts of agricultural developments on human, animal and ecosystem health and well-being may lead to more balanced assessments of the value of changes in one sector, and possible unintended consequences that need to be guarded against (Zinsstag *et al*., 2011) (see also Berger-González *et al*., Chapter 6, this volume).

Joint surveillance systems should ensure that the data between the sectors are harmonized from local to national levels. Surveillance systems should also be in a position to react to reported abnormal disease events. Existing systems are currently under evaluation and new approaches such as syndromic surveillance and use of alternative sources of information are being evaluated, but likewise need to show that they can generate useful information – and that they can use synergies. Using existing data, previously collected for another purpose, makes data integration more time-consuming. Too often, people are still sentinels for zoonotic disease outbreaks, despite the fact that zoonoses could be picked up earlier in animals. To note, surveillance and monitoring is not carried out on diseases alone. There is and should also be monitoring of stakeholders, demographic health indicators and response capacity.

Since One Health studies most often feature concurrent sampling of humans and animals, proper planning and implementation needs more attention, and may require more funding. Data acquired from different sources are associated with more causes of variation and possibly bias and confounding. Data quality is always paramount, being a particular challenge in a One Health study because every chain is only as strong as its weakest link and there are more links. Potential sources of errors range from selection bias to misclassification due to poor diagnostic test performance, all compromising the validity of the findings.

We note the following advantages of a One Health study design:

1. Simultaneous studies of human and animal health can better assess epidemiological linkages of zoonoses, including foodborne pathogens and antibiotic resistances that would otherwise not be seen.

2. Joint field research by mixed teams can serve as a nucleus for intersectoral collaboration and enhanced sharing of information in a country and a region.

3. A One Health perspective enhances intersectoral surveillance and communication (e.g. for rabies) and zoonotic disease outbreaks can be detected earlier if animals are used as sentinels. Joint task forces with participation from agencies with responsibility for human and animal health and the environment interpret risks together based on available data, promote consistent messages and coordinate preparedness and response.

4. Joint monitoring of an intervention (e.g. on brucellosis) can indicate if corrective actions are needed in the implementation of the livestock intervention and a decrease of human brucellosis incidence over time may be the most sensitive outcome of successful livestock vaccination.

5. Assessment of response and service provision capacity can lead to revived discussions on human and financial needs of sectors to manage zoonotic outbreaks.

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9 Surveillance and Response Conducted in a One Health Context

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Introduction

Worldwide, measures are taken to reduce (i.e. mitigate) the impact of diseases on the health of people, animals and plants. Policies are set by private industries, governments and international organizations. Mitigation policies follow the so-called policy cycle, from problem definition to policy development, implementation of mitigation measures and evaluation (Tsoukias *et al*., 2013). One Health and policy development is detailed in Chapter 29 (Rinchen *et al*., this volume).

Once an intervention is implemented, feedback is needed to assess whether it achieves the anticipated effect (Fig. 9.1). Such feedback is typically provided by the systematic collection of information – in other words – by surveillance. Surveillance has been defined as the 'ongoing data collection, analysis to convert this data into statistics, interpretation of this analysis to produce information and dissemination of information to those who can take appropriate action' (ECDC, 2008). In health, surveillance is central to the understanding of infectious pathogens, non-communicable diseases and other health threats. In addition to supporting the evaluation of mitigation measures, it assists in determining trends, including morbidity and mortality and the detection of timely changes in those trends. In systemically collecting information, surveillance systems also shape the policy cycle, in establishing problems, setting agendas, in policy development and implementation. Therefore, disease mitigation consists of two components: (i) an intervention component that aims to reduce occurrence of a hazard and/or to limit its consequences; and (ii) a surveillance component to provide information on the need for intervention and how to best implement it and to provide feedback on the impact of the intervention.

Any consideration of surveillance should be integrated into the process of making decisions on interventions. For such decisions, all relevant stakeholders such as farmers, veterinary services or international organizations should be included to establish the full policy context.

Recently, the term 'integrated surveillance' was used to indicate that a specific programme bridges several sectors. For example, *Campylobacter* infections affect both livestock and public health sectors. A strong case is made, therefore, for integrating mitigation and surveillance across sectors (Box 9.1). In this text, we use the term 'integrated surveillance' in the context of One Health to refer to surveillance based on a systemic, cross-sectoral, multi-stakeholder perspective to inform mitigation decisions with the aim to promote better health for all.

Depending on the stage of a mitigation programme in relation to hazard occurrence, the design of the surveillance accompanying the mitigation can vary (Häsler *et al*., 2011; Howe *et al*., 2013). Initially, when the dynamics and impact of a hazard are not yet well understood, surveillance is needed to provide more information and to complete knowledge and understanding. Once an intervention decision is taken and policy is set, surveillance data are

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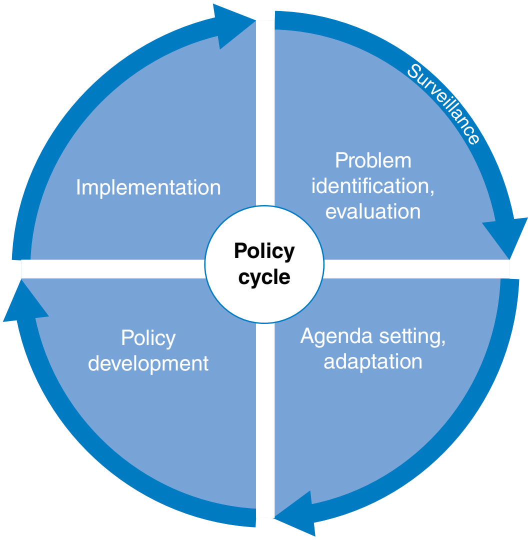

Fig. 9.1. Integration of surveillance and response in the policy cycle to achieve risk mitigation.

needed to assess progress. If the effect of the intervention is evaluated and found insufficient, adjustments are made (Fig. 9.1). Often, several iterations of this cycle are needed. This can be illustrated by the changing surveillance and intervention activities for bovine spongiform encephalopathy (BSE) that were gradually introduced, illustrating one of the costliest One Health incidents with global consequences still occurring (Box 9.2).

With progressive success of mitigation, the objective of control may shift towards elimination of the hazard. This is likely to impact the choice of intervention as well as the type of surveillance required. The latter will increasingly focus on demonstrating absence of the hazard rather than estimation of frequency of its occurrence. Such shift in surveillance objectives will lead to changes in surveillance design.

Both surveillance and mitigation activities are costly, as they involve material costs, labour, transport and other administrative and implementation expenses. Progress has been made to illustrate the economic aspects of disease mitigation, including the relationships between surveillance and interventions (Howe *et al.*, 2013) and the added value of cross-sectoral initiatives (Häsler *et al.*, Chapter 10, this volume). In the context of One Health, the economic relationships are complicated because interventions may occur in one sector while benefits accrue in another. In the BSE example (Box 9.2), feeding practices changed in the livestock sector to prevent disease and societal costs for humans. This multisector nature of mitigation programmes requires the impacts of hazard mitigation to be assessed in all sectors, animals as well as humans, and therefore, an integrated evaluation of surveillance is required. This is also illustrated in the case of antimicrobial resistance (AMR) (see Box 9.4 later in the chapter).

All veterinary and public health policies consume resources that then become unavailable for alternative issues. Thus, over the last decade, the use of formal evaluation has gained relevance. Evaluation is the part in the policy cycle that gives structured feedback on the impact and value of mitigation measures, and provides the basis for adjustments in the next iteration through the cycle (Fig. 9.1). General guidance on conducting evaluations is available, as is guidance specifically for animal and public health programmes (Peyre, 2020).

Advantages of Integrated Disease Mitigation

An integrated disease mitigation approach in the context of One Health has the ultimate goal of leading to healthier humans, animals, plants and ecosystems while optimizing the use of resources (Häsler *et al.*, 2013). In general, the advantages of integrated disease mitigation, which contribute to this goal, can be conceptualized in two main aspects:

- an increased effectiveness and economic efficiency of disease prevention and control due to enhanced information and system knowledge; and
- an increased sustainability and resilience of mitigation systems due to enhanced cross-sectoral collaboration.

We discuss these two hypotheses in detail below, while aspects focused on economic evaluation of One Health are discussed in Häsler *et al.* (Chapter 10, this volume).

Increased effectiveness and economic efficiency of disease prevention and control

Integrated approaches for disease mitigation permit early detection of emerging threats, which allows for timely responses (Rabinowitz *et al.*, 2009). They may also enhance system understanding of a health problem, improving the ability to identify the best intervention strategies for prevention and

Box 9.1. Defining integrated surveillance in the context of One Health – a continuing process.

The frequency of use of the term 'integrated surveillance' in the scientific literature has increased substantially over the last two decades. In different fields of health research, the term 'integrated surveillance' is understood differently and is not always related to cross-sectoral surveillance. Fewer than half of the articles using this term published since 2000 relate to surveillance at the human–animal–ecosystem interface. Although formal definitions are rarely provided by authors, 'integrated surveillance' is used to describe the integration, in a single surveillance system, of various sources or types of data, including, but not exclusively, data from human, animal and environment health. In public health literature, 'integrated surveillance' is used to describe surveillance systems that integrate data from multiple organizations, data on risk factors and outcomes, data from multiple geographical scales, or even the integration of interventions and surveillance activities.

Stärk *et al*. defined One Health surveillance as 'the systematic collection, validation, analysis, interpretation of data and dissemination of information collected on humans, animals and the environment to inform decisions for more effective, evidence and system-based health intervention' (Stärk *et al.*, 2015a, p. 125). The definition provided by Berezowski *et al*. (2015, p. 5) established One Health surveillance as 'the collaborative, ongoing, systematic collection and analysis of data from multiple domains to detect health related events and produce information which leads to actions aimed at attaining optimal health for people, animals, and the environment'. Subsequently, Aenishaenslin *et al*. (2019, unpublished results) proposed a revised definition of integrated surveillance as 'the systematic collection, analysis, interpretation of data and dissemination of information collected from different components of a system to provide a global, multidisciplinary, multi-perspective understanding of a health problem and to inform system-based decisions.' Applied to the context of One Health, the system includes the human, animal and ecosystem dimensions. This means that these dimensions should be reflected in the types of data collected and analysed within an integrated surveillance system. The dimensions should also be considered in interpretation and dissemination of the surveillance information produced by the system (Aenishaenslin *et al.*, 2019).

The collaborative dimension of 'integrated surveillance' is at the centre of the definition proposed by Bordier and colleagues. The authors defined a One health surveillance system as:

> a system in which collaborative efforts exist between at least two sectors (i.e. human health, animal health, plant health, food safety, wildlife and/or environmental health) at any stage of the surveillance process, to produce and disseminate information with the purpose of improving an aspect of human, animal or environmental health.
>
> (Bordier *et al.*, 2018, p. 2)

This definition underlines the importance of cross-sectoral organization and governance of surveillance in a One Health context. It also clarifies that integrated surveillance does not necessitate a fully centralized surveillance programme.

The use of the term 'integrated surveillance' might be perceived as a single, unified data collection, repository and analysis system. The latter could have extensive implications to the current responsibilities and institutional layout of the animal and human health services and, therefore, be perceived as a threat. On the other hand, a positive perception of the term 'collaboration', entailing sharing of information, joint risk assessment and communication, can be observed (Babo Martins, 2017). While the terms 'integrated' and 'collaborative' surveillance appear to be used interchangeably to refer to overall cross-sectorial surveillance activities, it is important to establish a common understanding of the roles and responsibilities in the design and implementation of surveillance and response in a One Health approach to ensure appropriate stakeholder engagement.

control, and leading to improved effectiveness of a response (Rabinowitz *et al.*, 2013). This can lead to better use of resources and increased economic efficiency. Increasing capacity to respond efficiently to disease is the primary advantage of integrated approaches and the reason why One Health is broadly endorsed nationally, regionally and internationally (WHO, 2014; Stärk *et al.*, 2015a).

The importance of the specific advantages will vary according to the hazards and their epidemiological status in the targeted populations. As defined by Häsler and colleagues (2011), the objectives of health surveillance differ according to disease status, within three stages of action to mitigate the disease: (i) sustainment; (ii) investigation; and (iii) implementation (Häsler *et al.*, 2011).

Box 9.2. Changing surveillance and mitigation for bovine spongiform encephalopathy (BSE).

Variant Creutzfeld-Jakob disease (vCJD), a fatal neurodegenerative disorder, is caused by prions and belongs to the group of transmissible spongiform encephalopathies (TSE) (Ghani *et al*., 2003). This hazard is characterized by a very long incubation period, possibly exceeding 50 years. The origin of BSE or mad cow disease in cattle, later described in humans as vCJD, is hypothesized to date back to contamination of processed animal protein and meat-and-bone meal (MBM) with material from animals with naturally occurring TSE in the UK in the 1970s (EFSA Panel on Biological Hazards, 2018).

Primary mitigation measures for vCJD, based on an understanding of transmission routes, included culling of cattle based on testing or age cohorts in infected herds and feed bans. Due to its status as a rare disease in both people and cattle, active surveillance and detection is challenging. Although transmission is possible through red blood cell or fresh frozen plasma transfusion (Bennett and Daraktchiev, 2013), the main public health risk of vCJD remains the alimentary route. In the UK alone, an estimated 3 million infected cattle entered the human food chain before massive surveillance and control measures were implemented (Smith and Bradley, 2003).

To date, the list of animals which suffer from prion disease remains incomplete, with theories even including marine mammals. However, to date, the main impact has been in sheep and cattle. This illustrates the challenge for decision makers to balance risks posed to human health versus impact on farmer livelihoods and export industry. One Health issues include the links of dietary exposure of cattle, economic incentives to both farmers (for more efficient use of feeds) and processors (to minimize energy and chemical use), and societal patterns of meat consumption (Nathanson *et al*., 1997; Cooper and Bird, 2003).

The trade disruption caused by BSE is huge and still prevents market access for beef from many countries. The economic losses caused by BSE are estimated at several billion Euros for heavily affected countries such as the UK and Germany. Due to the uncertain nature of this disease, policy makers undertook substantial precautionary measures for BSE intervention. An analysis by Benedictus *et al*. (2009) showed that under declining BSE prevalence and incidence, the cost-effectiveness of such measures becomes unfavourable and the measures difficult to justify. In the Netherlands, figures ranged from €4.3 million per human life year saved in 2002 to €17.7 million in 2005. Precaution-based legislation should incorporate checks on cost-effectiveness (Benedictus *et al*., 2009).

Despite the decreasing numbers of BSE cases, global efforts for surveillance in bovines continue. Diagnosis is only possible post mortem, so rapid testing, carcass traceability and trade logistics are paramount requirements for successful risk management. Due to the very limited number of vCJD cases, justification for disease control measures becomes increasingly difficult. International standards are not yet adjusted, although pressure to reduce testing programmes is likely to increase in the coming years (Wall *et al*., 2017).

The sustainment stage is when disease incidence is considered at an acceptable level and mitigation efforts aim to keep incidence under a certain threshold. At this stage, an integrated surveillance approach's biggest advantage is detection of early signs of emergence or increasing trends in sectors relevant for the disease epidemiological cycle. Early detection of a change in one sector (e.g. livestock) could indicate that change is likely to occur in another (e.g. the public health sector). A good example is early detection of an emerging zoonosis in a wildlife reservoir (see Box 9.3 on rabies in raccoons).

In the investigation stage, the incidence of a disease exceeds the acceptable level. To plan the most suitable intervention activities, information on the epidemiology of the hazard is collected. This includes parameters such as prevalence, morbidity, mortality and risk factors all by relevant population strata. This information is necessary to identify the best points of intervention, including the question of intersectoral responsibilities. In such a scenario, an integrated mitigation approach contributes to improve system understanding of the situation in all relevant sectors in order to target which interventions are most effective. For example, the integrated surveillance of antimicrobial use and resistance in different species and in humans will allow better understanding of how resistant bacteria or genes circulate between animal, plants and human reservoirs. This knowledge then informs about interventions most suitable to prevent resistance emergence overall in a given food system or ecosystem (see Box 9.4). Arbovirus risk management is

Box 9.3. Raccoon rabies: wildlife surveillance for public health benefit.

Raccoon rabies has been enzootic in most of the east coast of the USA for the last several decades. The northern spread has raised concern in Canada since the 1990s. The first rabies case was detected in a raccoon in Quebec near the US border in 2006. Surveillance was enhanced in a circular area around the first case. Three more rabid animals were found nearby the same year, with 66 new cases detected the next year (2007). The Government of Quebec then initiated a raccoon rabies control programme. Between 2006 and 2009, several million doses of oral rabies vaccine were distributed by air and ground over a 9500 km^2 area of southern Quebec province to control the outbreak and keep raccoon rabies away from more densely populated regions, including Montreal, only 40 km from the outbreak region. In 2008, 32 cases were detected, but only two new cases of rabies (raccoon rabies variant) were found in skunks in 2009.

Following this success, the government had to decide if they would continue to fund the surveillance programme and distribution of vaccines. To inform their decision, the Ministry of Health funded a project to quantify long-term costs and benefits of the mitigation programme. An epidemiological model estimated how the disease would spread in the raccoon population with and without the mitigation programme over a 12-year period from 2007 to 2018 (Shwiff *et al*., 2013). The costs of surveillance and control (i.e. vaccinating raccoons) were compared with potential costs of an increased risk for human exposure. The latter would lead to a higher frequency of administration of human post-exposure prophylaxis and increased frequency of animal (domestic and wildlife) testing for rabies over time. The study estimated the benefits of the mitigation programme to be C$47–53 million over the study period, with costs ranging from C$33 to C$49 million, indicating that every dollar spent on the raccoon rabies control programme would save between C$0.96 and C$1.55 in prevented societal cost (Shwiff *et al.*, 2013).

This study convinced the government to maintain the programme, which continues to run in the southern part of the province. Except for one rabies case detected in a raccoon in Quebec at the border of Ontario and the USA in 2015, no other cases have been recorded since 2009 (Government of Quebec, 2019).

Box 9.4. Multisector mitigation of antimicrobial resistance (AMR) emergence.

Antimicrobial usage in animals is the key driver for developing resistance in commensal and pathogenic bacteria in animals. Such resistance is of global public health concern because resistance determinants are shared directly and indirectly between animals and people. The transmission pathways are manifold. For occupationally exposed people, such as veterinarians, and also for animal owners, direct exposure regularly occurs when hygiene precautions are not taken. For individuals outside these risk groups, indirect exposure via animal-sourced food or the environment is the main exposure route. Although quantification of risk of exposure of people has not been achieved for most bacteria-substance combinations, AMR policies were developed over the last few years. In this context, all the relevant international organizations, such as the World Health Organization (WHO), the World Organisation for Animal Health (OIE) and the Food and Agriculture Organization of the United Nations (FAO), promote a One Health approach, including integrated surveillance programmes. However, only a few, mainly Western, countries have fully implemented and evaluated such programmes. One such country is Germany.

Germany implemented policies to reduce antimicrobial usage in livestock in 2014 (BMEL, 2019). The need for evaluation of effectiveness of measures was included in the legal text. Data were collected to allow the quantitative assessment of the policy both in the targeted livestock populations as well as along exposure pathways relevant to public health using a benchmarking approach. The evaluation report published in 2019 (BMEL, 2019) reported a reduction in usage for all livestock species and age categories. A reduction of more than 30% was achieved. It was also shown that reduced usage was linked to an improved resistance situation in bacteria (Moenninghoff *et al*., 2020). It was concluded that the policy and tools introduced were effective, and an effective prerequisite for further reduction. Similar programmes were implemented and evaluated, to some extent, in other European countries including Belgium, the Netherlands, France and the UK.

similar, where early detection of circulation in an animal population could trigger public health interventions ahead of viral circulation in humans (Box 9.5).

Finally, in the implementation stage, the intervention is identified and utilized, while surveillance provides feedback on its effectiveness. The advantage of an integrated mitigation approach at this stage lies in the choice of interventions and ease of comparison of their effectiveness. A complex intervention that includes measures in more than one sector may be the best option to mitigate the risks in a coherent manner. In addition, even if only one sector is targeted for intervention, the effects on disease trends should be measured in all relevant sectors to evaluate expected and unexpected impacts in humans, animals, plants and ecosystem health. For example, the effectiveness of mosquito control interventions implemented to control West Nile virus (WNV) is likely to be better assessed when data on mosquito density and confirmed cases in animals and in humans are monitored (Box 9.5).

If a hazard does not lead to health issues in one sector but could have disease consequences in another, integrated surveillance becomes essential. This is illustrated with foodborne diseases, where One Health approaches to surveillance and response have been adopted in several countries in Europe and the Americas (Galanis *et al*., 2012; Hulebak *et al*., 2013; Parmley *et al*., 2013). Commonly, integrated mitigation systems cover foodborne pathogens with high public health burdens, like *Salmonella* and *Campylobacter*. Often foodborne surveillance systems provide not only information on the enteric disease itself but also on AMR in the farm-to-fork continuum (CIPARS, 2015; Ford *et al*., 2015). Such mitigation systems use data collected at multiple stages of the food chain, through surveillance in the human, veterinary and food sectors, and through active or passive surveillance systems. By using joint analysis and interpretation, integrated surveillance provides stronger, more complete information and this adds value. In addition to the identification and confirmation of outbreaks and determining infection trends, integrated approaches to foodborne disease surveillance are important in determining transmission pathways and risk factors along the food chain. They allow understanding of the contribution that different foods make to foodborne illness, or food attribution (Hulebak *et al*., 2013; Ford *et al*., 2015). The use of a One Health approach can also be supported by use of whole genome sequencing in laboratory-based surveillance of foodborne outbreaks, by

Box 9.5. West Nile virus (WNV) surveillance for early warning.

For WNV, the potential to use animal and entomological information to detect viral circulation and undertake joint actions was recognized in Hungary (Krisztalovics *et al*., 2008) and Canada (Epp *et al*., 2008). Another operational example is the Emilia-Romagna system for WNV, where surveillance information generated in the public health and the animal health sectors is shared and has been used to guide public health interventions to mitigate risk of WNV transmission via blood transfusion since 2013 (Paternoster *et al*., 2017).

The Emilia-Romagna integrated WNV surveillance system includes human, entomological, ornithological and horse surveillance, and can trigger a range of public health interventions, including blood, tissue and organ screening, vector control and communication campaigns. Detailed description of this surveillance system was provided by Angelini *et al*. (2010) and Calzolari *et al*. (2012). It's One Health characteristics were further explored by Paternoster *et al*. (2017). The system resulted in early detection of viral circulation, where mosquitoes and birds were the first indicators of WNV circulation (Angelini *et al*., 2010). In 2013 and 2014, this early warning enabled detection of six infected blood donations before the onset of the first human cases of West Nile virus disease (WNVD) or West Nile fever in the same provinces. This meant avoidance of potential WNVD cases associated with transfusion of infected blood components through interception by the One Health system. The cost–benefit estimate of this system suggests that the One Health approach represented a cost savings in operational terms, and due to costs of hospitalization and compensation for transfusion-associated disease potentially avoided, benefits were estimated at €2.98 million.

More recently, results at the Italian national level for 2018 showed that the One Health approach for WNV surveillance detected viral circulation 9 days before symptom onset of the first confirmed human case, triggering timely implementation of blood and transplant safety measures (Riccardo *et al*., 2018).

adding the ability to discriminate relatedness to clinical outbreak isolates (Gerner-Smidt *et al.*, 2019).

Sustainable and resilient mitigation systems

A second advantage of integrated disease mitigation is the long-term development of sustainable and resilient cross-sectoral mitigation systems (Yasobant *et al.*, 2019). Resilience has been defined as the capacity of a system to absorb disturbance and reorganize in the face of a challenge (Walker *et al.*, 2004). By implementing integrated surveillance and response in a One Health context, a formal or informal cross-sectoral network of stakeholders who have learned to communicate, work and share responsibilities together is created and maintained over time. This in turn contributes to strengthen the resilience of the whole mitigation system for new challenges (e.g. emerging zoonoses). We argue that this aspect has not yet received adequate attention, neither from researchers nor from programme evaluators.

This advantage of system resilience is not disease or programme specific, as it concerns the capacity of a whole system to respond and adapt to upcoming changes. Thus, it generates benefits that are generally not reported in surveillance and programme evaluation. However, it may be the most important advantage of integrated disease mitigation in the long term. Such an advantage potentially includes intellectual capital, a stronger knowledge base, social capital, or other feelings of reassurance and trust, which may translate into tangible long-term benefits (Babo Martins *et al.*, 2016), as illustrated in Box 9.6.

Resilience is facilitated when an integrated disease mitigation programme runs over an extended period. Over time, the programme becomes institutionalized and results in sustainable organizations that collaborate effectively. Applied in a One Health context, implementation of an integrated approach forces organizations to overcome disciplinary and organizational separation (Kruk *et al.*, 2015). On the one hand, stakeholders and decision makers from collaborating organizations develop new interdisciplinary skills and competencies. On the other hand, intersectoral teams, processes and tools for management of programmes often become established by cooperating organizations, for example by development of formal collaboration or communication agreements (Kruk *et al.*, 2015). A better-skilled workforce with prepared institutions are used or adapted to solve similar or emerging intersectoral problems, increasing the

Box 9.6. One Health in operation to assess emerging risks in the UK.

During an acute incident affecting both veterinary and public health sectors, coordination becomes a key challenge in all countries where different administrative units are responsible for disease control in humans and animals. This is the case in the UK, where the Human Animal Infections and Risk Surveillance (HAIRS) group was implemented in 2004 following the BSE and vCJD experience. The HAIRS group is responsible for horizon scanning and risk assessment using a multiagency, multidisciplinary approach. This is achieved through monthly meetings with representatives of all relevant government agencies, where human and animal health practitioners are equally represented. At the meetings, unusual observations, syndromes, signals or incidents are discussed. Incidents are identified through systematic horizon scanning and routine activities. Decisions are taken on whether formal risk assessment is required or whether the issues should just be monitored before deciding on possible actions. Risk assessments are conducted qualitatively. Risk management and risk communication aspects are also discussed. Risk management recommendations are referred to the relevant competent authorities.

The HAIRS group demonstrated its effectiveness through a number of alerts, such as emergence of the Schmallenberg virus (Morgan, 2014). Key for success of this One Health group is that relationships across agencies are developed ahead of crisis situations. Through regular exchange, members of the group rely on a robust network of contacts, on whom they can rapidly call regarding the significance of unusual observations. This accelerates the response and increases the likelihood of a timely and effective response to One Health emergencies. That the group operates under agreed terms of reference and with detailed recording are important factors for effective communication and assured transparency. The HAIRS group acknowledges the influence of personalities and their impact on the operational success of multidisciplinary groups. Group composition and leadership appear to be key factors for success of One Health operations.

Box 9.7. Resilience and surveillance of AMR: the Canadian example.

The Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) was created in 2002. It is a national programme 'dedicated to the collection, integration, analysis, and communication of trends in antimicrobial use (AMU) and resistance (AMR) in selected bacteria from humans, animals, and animal-derived food sources in Canada' (PHAC, 2007). The system integrates data collected through passive and active surveillance from humans and several animal species at different locations on the food chain, such as on farms, at abattoirs and in retail meat stores (Deckert *et al.*, 2010; Dutil *et al.*, 2010; Agunos *et al.*, 2013, 2018; Parmley *et al.*, 2013).

The surveillance system is operated by the Public Health Agency of Canada and managed by a multidisciplinary team with expertise in different animal species, epidemiology and public health, among others. In addition, CIPARS created a national network composed of more than 600 stakeholders from interdisciplinary fields encompassing animal and public health, including livestock and poultry producers, veterinarians, physicians and licensing bodies, local, provincial and federal public health and animal health organizations, pharmaceutical organizations, drug and food regulators, animal and farm advocacy groups, and researchers. These stakeholders regularly discuss integrated information on AMR, which creates a unique space to share and discuss information and raise new concerns.

In response to new concerns, CIPARS has gradually included new components in the surveillance system to better represent evolving challenges. The programme started by integrating data on AMR from animal samples collected at abattoirs with data on AMR from sick animals and humans. Over 15 years the programme added other types of data, animal species, data collection on AMR of organisms in farm samples and in retail meat samples from different provinces, and data on the use of antimicrobials both in animal production and human health. The evolution of the surveillance programme was facilitated by the existence of a dedicated and skilled team, an active network of engaged stakeholders, and formalization of a set of processes transferable to other surveillance objectives. The capacity of CIPARS to adapt to changes over time is a good illustration of a resilient system, and is now considered to be one of the leading integrated surveillance systems for AMR worldwide (PHAC, 2007).

global mitigation system's resilience and sustainability, as shown in Box 9.7.

Challenges of Integrated Disease Mitigation

Despite the advantages of integrated disease mitigation at the human–animal–ecosystem interface, only a small proportion of surveillance and intervention programmes are currently operating in this way. Also, the extent of integration and the approaches used to achieve such integration differ widely across systems (Vrbova *et al.*, 2010). What is preventing progress towards integration?

Two main reasons explain the lack of adoption on a broader scale. First, integrated disease mitigation faces the general challenges of intersectoral action, which has been investigated in other fields where intersectoral actions are necessary (Danaher, 2011; Brooke-Sumner *et al.*, 2016). Second, there remains a lack of published evidence on the added value of integration. Even if the scientific community is mostly consensual regarding the need for and general desirability of integrated mitigation, specific examples are often lacking. This is probably because the implementation of integrated programmes remains hard, and the benefits still have to be quantified to convince decision makers. We illustrate both challenges below.

The challenges of intersectoral action

Intersectoral actions such as disease mitigation using a One Health approach require the collaboration and participation of more than one sector to address a specific problem and to yield the desired outcome. The challenges encountered when aiming to implement such actions can be related to organizational, disciplinary and language aspects.

Most national, regional and international governance bodies such as ministries or governments are designed to perform specific tasks under their authority. As such, shared or intersectoral governance of issues, such as a disease mitigation, is not necessarily foreseen. Responsibilities for human health, animal health, plant health and ecosystem health are generally separate with clear responsibilities. This structure causes a range of challenges including legal, ethical, political and economic issues (Stärk *et al.*, 2015).

Dos Santos Ribeiro and colleagues (2019) described these barriers for One Health implementation as present in the starting phase of intersectoral collaborations, in the execution of intersectoral actions, and in the monitoring and evaluation of cross-sectoral programmes. Before the implementation, incompatible mandates and institutional policies may complicate formal collaboration between institutions because of different priorities and lack of tools for shared decision making. At the execution phase, hurdles to sharing (data, information, resources) and a lack of resources (financial and organizational) to overcome these barriers, may be present and exacerbated by power imbalance between sectors. Finally, at the evaluation stage, collaborating institutions may suffer from an uneven distribution of costs and benefits between sectors. The latter is frequently observed when interventions are implemented in the animal health sector for the protection of public health (e.g. for preventing the transmission of a zoonotic agent, which has little or no impact on animal health).

In addition, interdisciplinary work is genuinely challenging regardless of the problem to which it is applied. Disciplinary paradigms and training strongly shape our practices, and professionals from different disciplines need time and patience to develop a common understanding, a shared language, and negotiated objectives and approaches. This challenge reflects ongoing debate regarding the definitions and conceptions of 'integrated surveillance' (see Box 9.1).

The lack of a priori interdisciplinary competencies of practitioners can also be attributed to the scarcity of interdisciplinary or One Health training programmes in universities and other institutions (Dos Santos Ribeiro *et al.*, 2019; Oura *et al.*, Chapter 28, this volume). This aspect has already been discussed in the context of medical education (Newhouse and Spring, 2010; Michael *et al.*, 2014). These interdisciplinary competencies need to be reinforced in stakeholders involved in integrated surveillance and mitigation in a One Health context (Stephen and Stemshorn, 2016). Ideally, such development is conducted during 'peace time' (i.e. in the absence of crisis and related pressure). Unfortunately, to develop such shared understanding is an effort and requires time and funds, which often only become available after things have gone wrong (Madhav *et al.*, 2017).

Barriers between disciplines and the need to overcome them are not specific to One Health. These challenges have also been documented when addressing reduction of health disparities, which is dependent on the collaboration of many disciplines and sectors relevant to social and environmental health determinants at local and global level (Danaher, 2011). Some innovative solutions to address this are already implemented, including functional One Health institutions with shared governance approaches, as illustrated by the Quebec Observatory for zoonosis and adaptation to climate change (Box 9.8).

Evidence needed on added value of integrated mitigation approaches

Very few studies have yet quantified the added value of integrated mitigation approaches in the context of One Health. Many researchers and decision makers have underlined the urgent need for a strong business case for One Health approaches in general (Stephen and Karesh, 2014; Queenan *et al.*, 2016; Baum *et al.*, 2017; Dos Santos Ribeiro *et al.*, 2019). If evidence of more rapid detection of disease and/or faster control of hazards were provided by using an integrated approach, this would provide convincing arguments to governments and funders to take this route. Perhaps it is not a coincidence that many One Health initiatives are started in low-income countries (Kamani *et al.*, 2015).

The policy cycle for disease mitigation is closed by evaluation (Fig. 9.1). However, existing evaluation frameworks for surveillance and intervention need to be extended to reach across sectors and adequately capture the value of integration. For AMR, several examples exist that link interventions in livestock (i.e. reduced antibiotic usage) to the resistance situation in bacteria relevant to humans (Box 9.4; Szelecsenyi *et al.*, Chapter 18, this volume). The key for such evaluation efforts is collection of data across sectors that allow linking interventions implemented in one sector to outcomes in another.

Babo Martins and colleagues (2016) proposed a conceptual framework for the economic evaluation of One Health surveillance. In this framework, the costs and benefits of the integrated surveillance system were compared to the costs and benefits of a past or hypothetical 'uni-sectoral' (i.e. not integrated) surveillance system. The use of this framework

Box 9.8. The Quebec Observatory for zoonosis and adaptation to climate change.

Zoonoses represent approximately 75% of emerging infectious diseases that affect humans (Vorou *et al*., 2007). Several factors are linked to this emergence. One important factor is climate change, which affects vector habitat suitability, disease reservoirs, vector range expansion and behaviour changes in humans, which increase risks and normal patterns of disease and health (Lake *et al*., 2009; Samy *et al*., 2016). To facilitate shared decision making in a One Health context, a new approach was implemented.

In the province of Quebec, Canada, the creation of a multi-organization observatory was funded to monitor the evolution of zoonoses in the context of climate change and propose specific adaption actions for surveillance, prevention and control. Both the governance and the actions of this observatory illustrate characteristics of a functional One Health institution.

The coordination of the Quebec Observatory is shared by two co-coordinators, one with an animal health background based at the Faculty of Veterinary Medicine of the University of Montreal and the other with a public health background based at the National Public Health Institute. Decisions are made within a panel of 22 members recruited to represent a range of disciplines and organizations relevant to integrated zoonosis management in the face of a changing climate. The disciplines include public health, microbiology, animal health, biology, wildlife, ecology, resilience science, environmental science, and policy.

A first action undertaken by the Quebec Observatory was to conduct a prioritization of zoonoses to guide surveillance, prevention and control interventions in the future. The group used a multicriteria decision analysis approach to evaluate and rank a list of zoonoses according to their importance and impact in the context of climate change. Evaluation of each zoonosis was based on a set of criteria to reflect actual and projected impacts on human, animal and environmental health, emergence capacity and socio-economic impact. Members of the observatory assigned the criteria according to their organization's priorities, and weights were applied in the analysis to rank the disease individually and globally. The exercise resulted in a list of prioritized zoonoses to be targeted for better research or surveillance (Simon *et al*., 2018). This approach allowed a collaborative, interdisciplinary and intersectoral prioritization, which integrated different expertise and priorities. Moreover, the discussions undertaken by the members during the prioritization process allowed stakeholders to confront ideas, perspectives and priority, and led to adoption of a common language, formalized in the definition of each criterion and their evaluation scale.

Multicriteria decision analysis has been used in other contexts for the prioritization of diseases or interventions using interdisciplinary and multi-stakeholder perspectives (Aenishaenslin *et al*., 2013; Brookes *et al*., 2015; Hongoh *et al*., 2016). For complex problems located at the human–animal–ecosystem interface, this method offers a systematic approach to integrate One Health in priority setting and policy formulation (Hitziger *et al*., 2018).

in different systems and different diseases showed that such evaluations present challenges in terms of availability of data. There is a need for systems that adequately capture expenditure as well as epidemiological information. When such information is available, as in the Box 9.5 example, the added value of integrated mitigation approaches can be made explicit.

Conclusions

The progressive consideration of One Health in aspects of disease surveillance and mitigation remains a subject of active and continuing debate across relevant disciplines. The impact of endemic diseases and emergence and re-emergence of health hazards relevant to both public and animal health continues, most importantly in the face of growing concerns around climate change. Research outputs and policy papers from recent years confirm sustained interest in these fields. The growing complexity of animal and public health challenges requires integrated consideration of the risk impact from actions taken or not taken in one sector on consequences in another.

The current surveillance and hazard management standards relevant to One Health were developed based on a more traditional understanding of responsibilities separated between sectors. Also, technical rather than organizational aspects tend to dominate the discussion. Even in such a situation, complexities persist between sectors. For example, risk awareness may differ between stakeholder groups. As part of efforts to promote One Health surveillance and risk management, it is noted that awareness and therefore engagement of non-veterinary professions remains limited. This observation holds true for many current surveillance and response activities. For example, in Switzerland a One Health platform was implemented at government level to coordinate risk management across sectors, particularly the medical, food, veterinary and environmental sectors. However, it remains challenging for the responsible secretariat to sustain engagement with their medical and food safety colleagues who question the relevance of the One Health approach to their responsibilities. Organizational and funding structures largely remain based on sector-specific allocation thus not encouraging collaborative programmes. This has been noted as some research funding bodies such as the Research Councils in the UK started to engage with other funders to create strategic funding partnerships for complex challenges like AMR (Medical Research Council, 2018). Such initiatives continue to be necessary and should lead to novel approaches to surveillance and hazard mitigation across sectors in the future.

Notable and encouraging examples of advanced collaborations in surveillance and interventions are available as described in previous sections. In some settings, resource constraints accelerated implementation of cross-sectorial collaboration because added value has become clear, sometimes even in the absence of economic quantification. In other situations, specific incidents or crises have forced organizations to collaborate. Having to establish operational links between organizations and sectors in the face of an emergency is clearly not ideal. This is recognized at the international level by, for example, the FAO, the OIE and the WHO, who formally collaborate to assure timely detection and management of international incidents across sectors.

The Tripartite Collaboration is founded on a formal agreement (FAO, OIE and WHO, 2017). Central objectives of the collaboration are detection and response to health threats at human–animal–ecosystem interfaces. The International Health Regulations (IHR) are a legally binding instrument managed by the WHO to prevent and respond to public health threats, including zoonoses. Since its creation in 2005, 194 countries have become signatories of the IHR. Since founding the IHR, the international community increasingly recognized that numerous health threats cannot be managed successfully using a uni-sectorial approach. Therefore, monitoring and evaluation activities implemented under the IHR currently also include assessment of the One Health capacity of a country. The objectives of the Joint External Evaluation (JEE) missions and the resulting reports are to enhance the assurance of collaboration, coordination and communication across sectors and thus to increase the resilience against trans-sectorial health threats. The JEE missions and joint guidelines are important instruments supporting advancement of integrated risk management in a One Health context. The published guide specifically addresses needs for joint surveillance and information sharing as well as collaboration in investigation and response to health threats (WHO, FAO and OIE, 2019).

Independently from the concept of One Health, risk analysis experts suggested over the last decade or so that management of complex and emerging risks such as climate change require new concepts and frameworks (Klinke and Renn, 2019). According to these authors, current risk management practices need to evolve. It was suggested that a formal role in policy development cannot be assigned to technical experts alone, but that all stakeholders and ultimately all citizens should contribute to the debate around management of complex risks. This is particularly relevant to risks that have significant technical uncertainty, which is often the case when affecting multiple sectors in a One Health context. As such, elements of conventional risk assessment would be complemented by risk characterization and evaluation, providing a new framework for risk governance (IRGC, 2017). Risk governance is proposed to follow a cyclic process including implementation, monitoring and review (Fig. 9.2). The main difference from conventional risk management is explicit inclusion of stakeholders and the wider society by using open debate and polling. Surveillance remains a key activity in this approach providing essential input at multiple levels, particularly to assess the impact of risk management.

Such considerations are relevant to the One Health debate because One Health risks often fulfil the criteria characterizing emerging and so-called systemic risks, such as complexity, uncertainty or ambiguity (IRGC, 2017). Also factors associated with risk emergence are often relevant in the One Health context (IRGC, 2010, 2015). For example, the management of AMR is considered a complex and emerging cross-sectoral risk (Szelecsenyi *et al.*, Chapter 18, this volume). Unsurprisingly, the proposed mitigation strategies to date mainly include

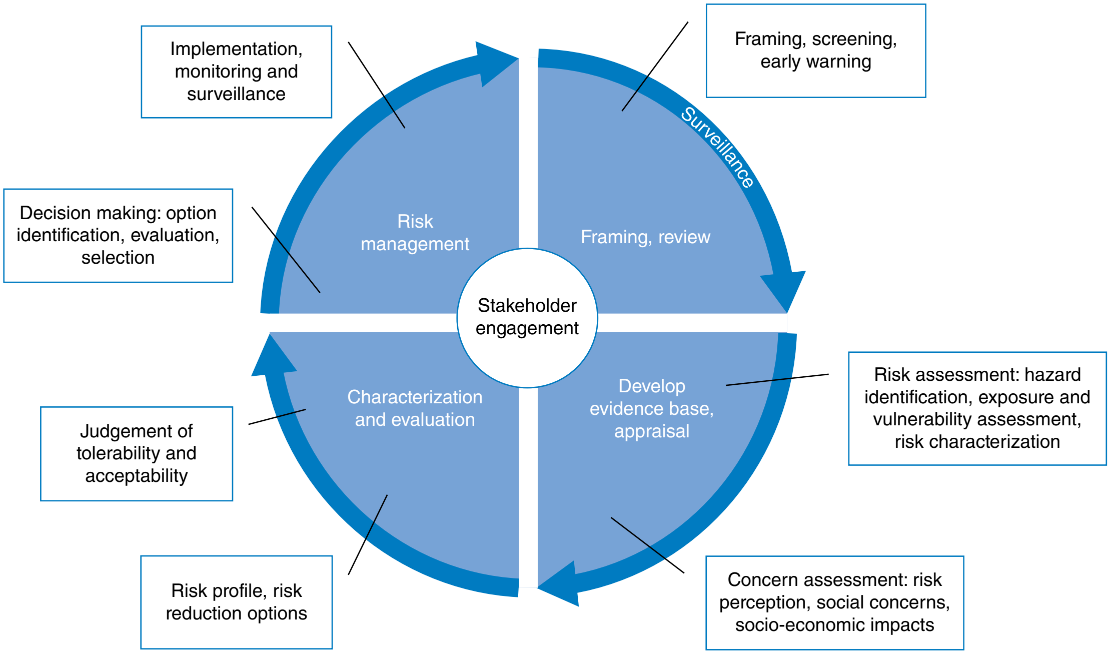

Fig. 9.2. Governance cycle for complex risks. Based on IRGC, 2017.

surveillance activities across sectors (e.g. European Commission, 2017). This is completely in line with the suggestions made in this chapter. While there is increasing debate of the problem due to increased awareness, which can further reduce usage, specific intervention strategies are lacking. Despite generic recommendations to increase investments into disease prevention, specific aspects such as defined intervention thresholds depending on the prevalence of resistance in certain substance-bacteria combinations are still lacking. An explicit debate of costs and benefits of reduced use and possible consequences on access to antibiotics in specific cases is needed. Societal aspects such as the changing role of pets in today's societies will need to be included (Hall *et al.*, 2017). First applications of this approach demonstrate that participative risk governance processes may result in varying risk management solutions in different countries (i.e. risk management solutions will have more variability) (Begemann *et al.*, 2018).

Significant progress has occurred in development of integrated surveillance and mitigation strategies in the context of One Health. Adapted approaches and tools to evaluate integrated disease surveillance and mitigation approaches are evolving rapidly, filling a gap identified by researchers and decision makers in the last decade. So far, research in this field focused on development of evaluation tools for individual programmes or policies (e.g. disease-specific surveillance systems), but approaches and methods to evaluate effective and resilient risk governance models in the context of One Health have not yet received sufficient attention. In an era where infectious diseases of animals, humans and plants are likely to emerge, and ecosystems may be complicated by climate change and other emerging risks, identification of the most effective risk governance models at the local and global scale are needed more than ever. This situation calls for strong involvement of social scientists in One Health governance research.

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10 One Health Economics

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Introduction

One Health is concerned with tackling problems such as food security, antimicrobial resistance, waterborne and foodborne diseases, malnutrition and environmental pollution to promote human, animal and ecosystem health. Closer cooperation between animal and human health has been shown to generate added value and has caused a shift towards increased integration of human and animal health interventions (Behravesh and Sinclair, 2019).

Despite the added value of One Health, the funding of zoonosis control has been proven to be difficult because public health sector awareness is low, and effective interventions are mostly outside the human health sector, targeting instead animal reservoirs or the environment. Economic analyses have played a key role in demonstrating an added value for closer cooperation across human and animal populations. While interventions may not be cost-effective for one sector alone, they may become cost-effective by taking an overall societal perspective with the benefits aggregated for all sectors.

In this chapter, we first present examples that demonstrate how economic analysis involving human and animal health sectors has become a central element for providing evidence of the added value of a One Health approach. We then reflect on new developments in One Health, in particular, approaches based on systems thinking, and their implications for economic analyses. Limitations in economic evaluations are discussed as well as untapped potential and opportunities for the future of One Health economics.

The Added Value of Cooperation between Animal and Human Health

Traditional techniques used in One Health economics to estimate the added value resulting from such cooperation and integration are cost–benefit and cost-effectiveness analyses. Several studies have demonstrated how both costs and benefits of diseases and disease control can cross from animals to humans, and vice versa. They can be categorized into four broad categories, namely: (i) increase in efficiency through cost-savings (e.g. stemming from the sharing of resources); (ii) generating benefits for humans by tackling disease in animal populations (and vice versa); (iii) achieving economic efficiency by expanding intervention programmes across sectors; and (iv) generating better knowledge and information by using integrative analyses. We present three case studies to illustrate this added value.

Joint human and animal vaccination services for mobile pastoralists in Chad

The Chadian pastoralist example provides clear evidence of the cost savings which can be made when health interventions target both people and livestock. Mobile pastoralists in Chad live closely together with the animals that form the basis of

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their livelihood. They live a mobile lifestyle in perpetual search of fodder and water for their livestock. As a result, they are almost completely excluded from currently available health services. Aiming towards a better understanding of the health status of pastoralists and their animals, researchers chose an integrated approach with a mixed team of veterinarians and public health personnel (Berger-González *et al.*, Chapter 6, this volume; Schelling and Hattendorf, Chapter 8, this volume). During these initial studies, pastoralists were also interviewed about their perceptions of human and animal vaccinations. It was found that the pastoralists reported a relatively high proportion of vaccinated cattle, whereas the vaccination coverage of children and women seemed very low. Based on these observations, joint health services were developed together with the Chadian public health and veterinary authorities (Schelling *et al.*, 2007). When veterinarians, who were mobile, planned a vaccination campaign for cattle, they took along public health personnel who would then vaccinate children and women. Joint vaccination campaigns were operated strictly separately by veterinary and medical personnel, but both transport and the cold chain for vaccines were shared. The cost of running animal and public health services separately was compared to the cost of operating them jointly. The cost savings from joint human and animal health vaccine delivery was 15% when compared to providing separate human and veterinary services. Thus, combined human–animal vaccination campaigns may be not only cheaper, but they may also notably increase the percentage of humans, and perhaps even animals, vaccinated.

Cross-sector analysis of brucellosis control in Mongolia

Brucellosis is a zoonotic disease which causes late stage abortion in animals. It is one of the most important zoonoses worldwide, occurring mostly in areas with extensive production of small ruminants and cattle. Humans become infected by direct exposure while working as farmers, veterinarians or butchers, or through the consumption of unpasteurized milk and milk products. Human brucellosis is a severe chronic disease, characterized by recurrent fever and pain that can put people out of work for long periods (Dean *et al.*, 2012a,b). Brucellosis re-emerged as a major preventable disease in Mongolia after 1990, when the political and economic system changed from a socialist to a liberal market rule. Health and veterinary service provision collapsed, leading to a rapid increase in human cases. International experts recommended to the World Health Organization (WHO) that Mongolia should reinstate livestock mass vaccination to prevent brucellosis in humans. The question investigated was: what is the effect of mass vaccination of livestock on human health? The first livestock–human brucellosis transmission model was developed as a backbone for the economic assessment (Chitnis *et al.*, Chapter 12, this volume; Schelling *et al.*, Chapter 20, this volume) to model costs and benefits in the private and public sectors for both human health and livestock production simultaneously. Data for the economic analysis were collected from government statistics and health information systems. Patient interviews revealed very important information on private costs, such as private out-of-pocket expenses for transportation, drugs and informal treatments (i.e. by traditional healers). Where data were missing, especially for livestock production, Delphi panels were used (i.e. groups of experts interviewed for their opinion regarding information that is not readily available). The savings to human public health totalled roughly US$3 million, which was notably lower than the US$8 million cost of intervention. From a public health perspective, it would therefore not be cost-effective to mass vaccinate the livestock to avert the public health cost. Combined savings, however, from the reduced burden of disease in human health, households and animal production totalled US$26 million, over three times the US$8 million cost of the intervention. This prime example of the added value of One Health showed that interventions become cost-effective when viewed from a broader societal perspective (Roth *et al.*, 2003).

Dog rabies elimination in an African city

Rabies is a viral disease transmitted most often in urban areas of Africa and Asia through dog bites (Léchenne *et al.*, Chapter 19, this volume). Human cases, which are invariably fatal, can be prevented by post-exposure prophylaxis (PEP), which is an active and passive immunization following a bite from a dog suspected to be rabid. Alternatively, dog rabies, and indirectly human rabies, can be eliminated by mass dog vaccination campaigns. Similar to the previously described example of brucellosis, one might ask: is it cost-effective to prevent human rabies by mass vaccination of dogs in an African city? This question arises through consideration of different intervention options. Indeed, WHO recommends both human PEP and dog mass vaccination, but the latter is rarely implemented in a systematic way. Based on years of weekly observations of dog rabies cases and the number of exposed humans in N'Djamena, Chad, transmission parameters of a dog–human rabies transmission model were estimated and used to simulate the effects of different interventions (Chitnis *et al.*, Chapter 12, this volume). Based on experiences from small vaccination trials, the cost of dog mass vaccination and human PEP was recorded to estimate the comparative cost of human PEP alone versus human PEP with dog mass vaccination. The cumulative cost of human PEP alone increases continuously because of ongoing transmission of dog rabies. In N'Djamena, every year more than 100 people are bitten by a rabid dog and, on average, seven of them die from rabies (Frey *et al.*, 2013). The cumulative cost of a single dog mass vaccination campaign with human PEP starts at a higher level, at approximately US$43,000, but does not increase much further because the transmission of dog rabies is interrupted, resulting in fewer human cases and thus less human PEP cost. The cumulated costs of human PEP with a single dog mass vaccination and human PEP alone reach the point of break-even at 5 years after the start of the interventions. After this period, the intervention of human PEP with a single dog mass vaccination is less costly than the cost of human PEP alone. The cost-effectiveness of the two compared interventions is expressed in cost per disability-adjusted life year (DALY) averted (Fig. 10.1).

For the first years after the single vaccination intervention, cost-effectiveness of human PEP with dog mass vaccination is lower than human PEP alone, resulting in a higher cost per DALY averted. However, in year six and beyond, human PEP with dog mass vaccination is more cost-effective. The break-even points between the two interventions depend highly on the dog–human ratio and dog–human behaviour in a given location.

Methodological Considerations and Metrics

A commonality of these studies is that they rely on cost-effectiveness analysis (CEA) or cost-utility analysis (CUA) to value human health outcomes (e.g. cost per DALY averted), and on cost–benefit analysis (CBA) of non-human health outcomes including animal health. Multi-sector disease control initiatives will usually involve decision makers from these different sectors with perspectives on how to evaluate and rank economic outcomes which vary greatly. Thus, a person in the health sector will

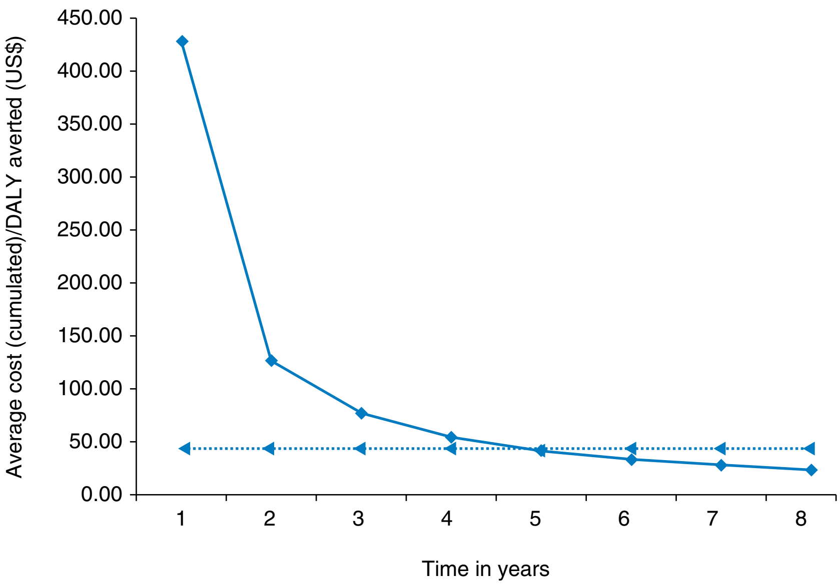

Fig. 10.1. Average and discounted cost-effectiveness of human post-exposure prophylaxis (PEP) alone (dotted line) and human PEP with dog vaccination (solid line). DALY, disability-adjusted life year. Adapted from Zinsstag *et al.*, 2009.

be looking at interventions that increase the number of health-adjusted life years (HALYs), whether these are measured as an increase in quality-adjusted life years (QALYs) or a decrease in DALYs. In the animal health sector, economists will usually be looking at monetary gains from livestock deaths avoided and productivity gains. Both animal and human health sectors will hope to save costs on treatment and prevention of disease in their populations of interest. Looking specifically at zoonotic diseases, the interventions will very often be targeting the animal reservoir while the benefits are mainly felt in the human sector.

For the example of rabies, reducing the number of dogs that could spread rabies by controlling feral dog populations and vaccinating dogs is a key component of costs. In an economic assessment undertaken in Colombo City, Sri Lanka, 80% of additional costs for rabies control were in the animal sector (Häsler *et al.*, 2014). The estimated benefits were in terms of DALYs averted, a net reduction in dog suffering (expressed as a qualitative score) and increased social acceptance of dogs. For the case of brucellosis in Mongolia discussed above (Roth *et al.*, 2003) the planned intervention was vaccination of cattle and small ruminants, and thus 100% of the costs were in the livestock sector. It was estimated that there would be significant savings on treating human patients, but importantly also substantial benefits to the livestock sector where brucellosis causes significant losses, which accounted for 58% of the total benefits calculated. An instructive third example is provided by a project implementing a multi-disease multi-sector One Health disease control approach in the Lao People's Democratic Republic (Lao PDR) (Okello *et al.*, 2018). People received albendazole in the form of a mass drug administration to control both *Taenia solium* and soil-transmitted helminths (STH), while pigs were vaccinated against classical swine fever and *T. solium* and given oxfendazole. In this case, 35% of the costs were in the human health sector. There being substantial benefits to pig production, these accounted for over 99% of the monetary benefits; however, the reduction in the incidence of neurocysticercosis and STH generated a substantial human health benefit valued in DALYs.

These very different outcomes, where costs and benefits can be very much skewed towards one sector or the other makes it difficult for policy makers to decide how to allocate scarce funding.

In human health economics, the convention is usually to use a measure of cost-effectiveness, where cost is measured in monetary units and then divided by a non-monetary HALY. Thus, one way of presenting an economic evaluation of an intervention to control a zoonotic disease would be to group all the monetary costs and benefits, and compare them to the HALYs. This is the 'aggregate net cost' method. Essentially, this is what Häsler *et al.* (2014) do for rabies, where the costs of the intervention are additional costs for improved health care and the implementation of rabies control measures in dog populations. The result is a respectable cost-effectiveness ratio (CER) of US$1401 per DALY averted, at a time when annual gross domestic product (GDP) was US$2860 per capita. However, very importantly, it all falls apart when there are substantial monetary benefits to animal health, because the disease affects livestock. Then, it can happen that the monetary benefits outweigh the monetary costs, so that the numerator in the equation is negative. The Mongolia example yields a figure of US$-373 per DALY averted. People, especially in the health sector, find this very hard to interpret. It seems to imply that the livestock sector should just move forward and deal with the problem.

In order to find a more holistic way of analysing the dual benefits from zoonosis control as well as a more equitable way of dividing the financial responsibility between the human and animal health sectors, the 'separable costs' method was developed by Roth *et al.* (2003). This suggested dividing up the total costs of the intervention between the sectors in line with the total proportion of monetary benefits. For the Mongolia example, indicated above, 42% of the monetary benefits come to the human health sector. If the human health sector were to be responsible for 42% of the costs, this would yield a cost-effectiveness ratio (CER) of US$71 per DALY averted, well below the annual per capita GDP at the time of the study of US$410. This method has been widely and successfully used and recommended (Narrod *et al.*, 2012). Nevertheless, there are downsides. For example, for the Lao PDR example, where 99% of monetary benefits came to the pig sector, it would imply that this should bear 99% of the costs, so that the CER for the human health intervention would be a minimal US$0.70 per DALY averted. In effect, the separable costs method allocates cost without taking into account the value of the DALYs averted.

An obvious way around this would be to simply put a monetary value on the DALY. This is attractive because it uses a single metric, money, which most decision makers understand. As early as the mid-1990s it was suggested by the WHO Ad Hoc Committee on Health Research Relating to Future Intervention Options (1996) under the chairmanship of Jeffrey Sachs, an economist of international repute, that the DALY could be valued at between 1 and 3 years' per capita GDP. This has been implicitly accepted in the CER thresholds now adopted by WHO (Tan-Torres Edejer *et al.*, 2003), which consider a cost of less than 1 year's per capita GDP per DALY averted to be very good value for money and between 1 and 3 years', good value for money. This 'benefit–cost analysis' approach effectively monetarizes all components. The proportion of benefits quantified for each sector now reflects both human and animal benefits. Thus, for human health in the Mongolia example it increases significantly from 42% to 67% and dramatically in the Lao PDR example from 0.25% to 88%. However, this runs against the moral principle underpinning the DALY, which underlies its success, wide acceptance and adoption as a global measure of the burden of disease in people: that a life is a life, no matter whose it is nor where they live.

To resolve the issues around the three methods outlined above, there has been a growing debate about creating an animal HALY. However, trying to formulate this rapidly runs into some big issues. Maximizing life is not a goal for animal keepers in many situations. Wildlife generally live longer in zoos, but no one would advocate the wholesale transfer of animals to zoos. Livestock producers would like their animals to attain their ideal economic lifespan, which for some animals is quite short, for example pigs. It is possible to identify premature mortality, but the desirable lifespan varies greatly between production systems. Some animals are culled for relatively minor ailments such as leg injuries, because keeping them alive is not economic for the livestock keeper so disability weights are both higher for many animals and very much linked to their function and the production system involved. Within species, animals can have very different roles. Ultimately, even if it were possible to calculate HALYs for different species, how would these be ranked against each other, from a giant panda, via different wildlife, to livestock, pets, and on to, for instance, a disease-carrying rat. Some have talked of a productivity-adjusted life year (PALY) for livestock, but attempts to quantify it foundered on some of the issues mentioned above. For the category of pet dogs, whose owners want them to live as long and healthy a life as possible, a paper calculated welfare-adjusted life years (WALYs) (Teng *et al.*, 2018). This concept works for companion animals, but would be difficult to generalize to include livestock, even if an emphasis on welfare were included.

In 2018, the concept of the zoonotic DALY (zDALY) was presented to examine livestock losses in terms of a time trade-off (Torgerson *et al.*, 2018). For example, looking at approximate orders of magnitude, if an African farmer whose income is US$1000/year, loses a cow valued at US$500, it would take 6 months' work to recoup loss. If a European farmer whose income is US$25,000/year loses a cow worth US$1000 it would only take 2 weeks work to recoup his loss. Based on this, Torgerson *et al.* (2018) propose a metric called the 'animal loss equivalent' or ALE. The monetary losses due to a zoonotic disease in livestock could be divided by annual per capita GDP to obtain a time trade-off value, which could be assimilated with the conventionally calculated DALYs for human health losses, to produce a hybrid metric, the zDALY. This would represent the total losses from disease in people and animals. The costs from controlling the disease could then be divided by the number of zDALYs averted to produce a CER in the conventional way. Going back to our examples, for rabies in Colombo the CER would be unchanged, as there were no livestock losses. For the Mongolia example, the CER is very similar to that obtained using the separable costs method, at US$72 per DALY averted. Because 1 year's per capita GDP is used as the numéraire for converting monetary livestock losses to ALEs, the share of benefits to human health is identical to that in the benefit–cost method at 67%. For the Lao PDR project the CER becomes US$234, highly cost-effective in relation to an average annual per capita GDP of US$1793 at the time the study was undertaken. Once again, the share of benefits going to human health is the same as for the benefit–cost method, at 88%. Thus, the benefit-cost method and the zDALY by using per capita GDP as a numéraire provide similar results, one with benefits in monetary terms, one with benefits in terms of a hybrid metric (Table 10.1). The various points raised are discussed in detail elsewhere (Shaw *et al.*, 2017).

Table 10.1. Results obtained using different methods for analysing the costs and benefits of controlling *Taenia solium*, classical swine fever and soil-transmitted helminths in the Lao PDR.[a] Based on figures from Okello *et al*., 2018.

	Indicators			
Method	Percentage of benefits to human health	Percentage of costs for human health	CER: US$ per DALY averted	Benefit–cost ratio
Aggregate net cost	0.25%	35%	$14	0.9
Separable costs	0.25%	0.25%	$0.70	0.9
CBA	88%	35%	NA	7.7
zDALY	88%	35%	$234	NA

[a]CBA, cost–benefit analysis; CER, cost-effective ratio; DALY, disability-adjusted life year; NA, not applicable; zDALY, zoonotic DALY.

In the same way as converting DALYs to a monetary value, the zDALY is open to the criticism that it implicitly puts a monetary value on people's time – and values this differently in different countries, thus involving ethical and equity concerns (Wettlaufer *et al*., Chapter 11, this volume). Thus it may be that the zDALY is best suited to within-country rather than cross-country comparisons. Set against these concerns is the great advantage of gaining some idea of the total benefits received in a One Health context and of the relative importance of livestock and human losses in different diseases. Some of the criticisms could be countered by using 3 years' GDP, rather than just 1 year's, as the weight for converting DALYs to money or livestock losses to ALEs. This would weigh the benefits more towards the human health sector. While anthropocentric, it has the intuitive appeal, in terms of time trade-off, that in an ideal world people only spend a third of their time working, and it echoes the cost-effectiveness thresholds now adopted by WHO. Ultimately the zDALY approach should be seen as a somewhat artificial device, which provides consistent results highlighting the relative financial importance of human and animal health losses due to zoonotic diseases, rather than as an intrinsic assessment of the value of life.

For humans, other attempts to put monetary values on human life do exist, such as life insurances or risk-based assessments including the value of a statistical life (VSL), which is estimated on the basis of people's recorded expenditures to avoid risky situations which might lead to death. Unsurprisingly, these attempts yield widely different values within different economic and social contexts. As with WHO's cost-effectiveness thresholds using multiples of GDP, such monetary values may be helpful in guiding expenditure levels on health interventions, subject to the considerations mentioned above.

Despite the obvious advantages of CEA and CBA (Table 10.2) and their usefulness in One Health studies as explained above, careful consideration of the assumptions involved is needed in order to identify cases where these methods might lead to misleading conclusions. If so, standard CEA or CBA might need to be adapted or combined with alternative approaches to provide useful insights. Theses methodological issues are discussed below in more detail.

Moving Beyond CEA and CBA

One Health systems thinking and setting of boundaries

As seen above, One Health economics has often focused on evaluating initiatives including assessments and comparisons of costs and outcomes. In that sense, it was primarily a tool to aid decision making. In order to evaluate an intervention in a complex system, we often need to widen the scope of economic evaluation and put more emphasis on understanding how and for whom the relevant costs and outcomes are generated. This can be achieved by looking at complex systems that are characterized by non-linear dynamics and emergent properties at the system level. In other words, One Health – and the evaluation thereof – must consider the integration of the needs, values and opinions of numerous disciplines, sectors and people from all levels of society in an interdisciplinary or transdisciplinary process rooted in systems thinking (Rüegg *et al*., 2018).

When observing, studying or influencing a system using systems thinking, the researcher, decision maker or practitioner commonly allocates boundaries to the system as a way of simplifying and creating a manageable entity. These boundaries include consideration

Table 10.2. Overview of characteristics of cost-effectiveness, cost-utility and cost–benefit analyses (CEA, CUA and CBA), their advantages and limitations.

Characteristic	CEA/CUA	CBA
Theoretical background	• Extra-welfarist/decision-maker approaches: health is the social objective to be maximized by the decision maker under possible budget (resource) constraints, the differences in individual preferences/utilities are not taken into consideration	• Welfare economics: preference for health is expressed in terms of individual willingness to pay (WTP) for it compared to possible alternative uses of the available resources (opportunity cost) • Social preference is subject to Paretian dominance (one solution is preferable to another if it provides a better result for someone without implying a worse one for someone else)
Point of view of the analysis	• Sectoral, multisectoral, or societal perspective	• Societal perspective
Main common operating concepts	• Costs: the value of resources consumed by the health and non-health sectors and by patient families (including productivity losses) for a given course of action expressed in monetary terms. Resource consumption corresponds to a welfare decrease since resources are distracted from other possible uses (opportunity cost) • Consequences: the outcomes of a course of action in terms of changes in the health state, other values created, and resources saved. Such outcomes correspond to welfare increases (benefits) • Monetary values are deducted from market prices for market goods, and with various evaluation methods (e.g. contingency evaluation) for non-market goods • Time preference: the preference of individuals and society for postponing costs and pains, and anticipating gains and pleasure expressed through the operation of discounting and the application of a social rate of time preference	
Main specific operating concepts	• Effectiveness: an estimate of the outcome (desired effect) of a given course of action, measured in natural units (in CEA) or utility (in terms of health-related quality of life) for beneficiaries (in CUA) • Incremental cost-effectiveness ratio (ICER): incremental cost per additional unit of outcome indicating the cost-effectiveness of a given course of action with respect to the counterfactuals	• WTP expresses in monetary terms the preference of an individual for an increase in welfare (e.g. to achieve a benefit or avoid a pain) • Benefits: the value of welfare increases consequent to a course of action expressed in monetary values • Net present value: difference between the discounted monetary value of all the benefits (welfare increase) and all the costs (welfare decrease) of a given course of action
Pros	• Conceptually simple and intuitive and can be interpreted by a wider audience than CBA • Outcomes expressed in natural units can be measured more accurately and involve fewer assumptions than CBA • CUA metrics allow comparison in terms of cost/utility created between interventions targeting different aspects of health • In general, CEA and CUA require reduced financial effort compared to CBA • CEA is adaptable to application in different sectors (human and animal health, environment)	• Evaluates trans-sectoral costs and benefits beyond the health sector • The purely monetary metrics allow an aggregated evaluation of all types of outcomes and comparison of the value for society between interventions targeting even unrelated sectors of society • Its theoretical structure makes it applicable to evaluation of all types of interventions

Cons	• The CEA one-dimensional effectiveness indicator prevents direct comparisons of alternatives that cannot be referred to the same physical parameter • In CEA, the efficiency indicator may be imperfectly correlated to the real objective of the initiative • CUA indicators result from aggregation of subjective qualitative judgements, which makes this metric more conceptual and less objective than CEA indicators	• Requires structured and complex operations (e.g. primary data from different sectors) • Relies on strong conceptual assumptions, which are not always realistic (e.g. assuming unbound rationality) • Evaluation methods may not be reliable (e.g. contingent valuation relies on preferences declared by interviewees, not on real consumer choices) • May require important financial efforts to be performed • The use of the monetary values for certain non-marketed goods like the health state or the environmental quality is subject to ethical concerns, as well as the application of discounting to such values (i.e. tyranny of discounting)

of aims, stakeholders, geographical, temporal, institutional and governance dimensions (Rüegg *et al.*, 2018). The drawing of boundaries to define the system of interest within its wider context allows separating the elements that are of direct concern from those of broader impact. Some boundaries are generally accepted and often uncontroversial such as specifically created units, like a food producing company with individual departments, or naturally occurring distinct systems that are recognized as particular entities (e.g. a moorland). An important characteristic here is that these definitions are based on widely shared and commonly agreed perceptions. In health systems, the common conceptualization of recognized systems in what is called sectors has strong historical roots and has resulted in the siloed structures with distinct sectors taking care of public, animal and ecosystem health and few cross-cutting linkages. Even within one sector, there are many historical, accepted delineations that have become institutionalized and are therefore resistant to change. One such example is the decision after World War II to separate national health and social care services in the UK and their units of governance with national organizational hierarchies in charge of health and local authorities in charge of social care (The Health Foundation, 2020). This resulted in inefficiencies in continued, people-centred support structures and a perpetual debate over the responsibilities and funding of the organizations involved.

With the rise of cross-cutting, complex challenges such as antimicrobial resistance, climate change and foodborne, waterborne and zoonotic diseases, existing boundaries are constantly challenged, and calls for transcending, more truly integrative approaches and practices are numerous (Wallace *et al.*, 2014; Assmuth *et al.*, 2019). However, because of the existing organizational hierarchies and associated institutionalization, resource allocation and governance structures, there is an inertia to change in these systems. Consequently, there is a delay in generating possible benefits from improved well-being of humans, other animals and ecosystems. For example, supermarkets, food corporations, retailers and restaurants contribute substantially to GDP while often adding to the problems of waste, emissions, unsustainable resource use and obesity (see also Gordon *et al.*, Chapter 25, this volume). The negative impacts of obesity on cardiovascular disease, diabetes and other illnesses (Pi-Sunyer, 2009) are not borne by food systems, but by health and social care services. In an economic analysis where the food industry is the unit of interest, the negative health consequences caused by malnutrition can be considered a negative externality that needs to be absorbed by other structures in society; the societal costs far outweigh the private costs (Karnani *et al.*, 2016).

When the boundary of an economic analysis is chosen too narrowly, there is risk that a problem is only solved temporarily or that we create problems elsewhere, either geographically, socially or over time (Meadows, 2008). In One Health, we need to redefine system boundaries and analyse their elements with the health of people, animals and ecosystems as a central purpose. But such a change in approach requires resources. Decision makers, funders, governments and private industry need to see evidence of the added value of using a One Health approach with new scales of analyses, operations, governance and funding.

Implications for economic analysis

Most One Health contexts can be understood as involving complex systems. Traditional methods in economic evaluation assume linear and univocal causality (Smith and Petticrew, 2010). Effects are generally examined independently of their context (known as a *ceteris paribus* or 'all other things being equal' assumption) (Jan, 1998). Extrapolations from linear, short-term estimates based on traditional methods, therefore, can be inaccurate. Moreover, interventions can change context variables in important ways, invalidating simplistic *ceteris paribus* assumptions (Jan, 1998). Non-linear dynamics including feedback loops can lead to unexpected behaviour over time, or when scaling up, to the appearance of 'tipping points' (Shiell *et al.*, 2008). Experts have therefore advocated for the use of methods that can incorporate complexity and non-linearity into economic evaluation. These include mixed-methods 'macro' approaches (Smith and Petticrew, 2010) and system dynamics or, more generally, systems thinking (Shiell *et al.*, 2008).

The challenges discussed relate to characteristics of One Health which violate many of the assumptions involved in traditional evaluation. These characteristics are not exclusive to One Health, and can be found, individually or in various combinations, in other contexts. By focusing on common characteristics, we can draw relevant insights for One Health, based on the growing literature around economic evaluation in related contexts. Areas that offer important, at least partial, parallels include evaluation of public health and population-wide interventions (Weatherly *et al.*, 2009; Smith and Petticrew, 2010), multisector interventions (Remme *et al.*, 2017), complex interventions with strong non-health outcomes (Payne *et al.*, 2013) and climate change policy (Burke *et al.*, 2016). We provide a brief overview of the main issues and identify recommendations to address these based on existing literature. The issues we discuss are split into distinct points for easier interpretation, but they are highly interrelated and often overlap. The main insights from this section are summarized in Table 10.3.

Challenges When Dealing With Complex Systems and Non-linear Causality in Economic Analyses

Incorporating equity and sustainability concerns within efficiency-oriented maximizing approaches

Although efficiency is an important consideration for One Health initiatives, equity and sustainability are also core goals of the approach (Rüegg *et al.*, 2018). Economic evaluation, however, is mainly oriented towards efficiency, aiming to maximize an outcome with limited resources (Coast, 2004). The

Table 10.3. Characteristics of One Health initiatives versus assumptions of standard economic evaluation approaches, challenges and recommendations based on existing literature applied to interventions with overlapping characteristics

One Health characteristics	Standard economic evaluation assumptions	Challenges	Recommendations
Addressing complex systems, non-linear causality	Linear causality, *ceteris paribus* assumptions	How to capture feedback loops and tipping points? How to extrapolate in time or to larger scales?	Systems thinking (e.g. system dynamics, agent-based models) macro assessment
Often aimed at the system/population level	Methodological individualism	How to assess emergent system properties (resilience, interconnectedness, equity)? How to capture system-level feedbacks?	Systems thinking (e.g. system dynamics, agent-based models) macro assessment
Equity and sustainability are core values/goals	Maximizing, efficiency oriented	How to incorporate equity and sustainability?	Needs-based approaches, capabilities, research into equity weighting and equity trade-offs
Multiple goals besides health	Health as the main (only) goal/monetized outcomes for non-health sector	How to combine different outcomes and translate into decision making?	Capabilities approach, cost-consequence analysis, process measures (empowerment), multi-criteria decision analysis (MCDA)
Multiple sectors and stakeholders involved	Single health sector/ payer or aggregate societal perspective	How to allocate cost? How to choose appropriate outcome measures?	Sector-specific summary measures, cost allocation approaches based on marginal utility of budget
Interventions can change values and preferences of involved actors in important ways	Preferences assumed intrinsic and static	How to incorporate changing values due to increased information or interaction with actors in other areas of the system?	Participative value elicitation for different stakeholders in the system, dynamic endogenous preference modelling including estimates of the crowding-out or crowding-in effects of intervention
Process is key	Black-box, consequentialist approach	How to account for process?	Incorporate institutional economics approaches, process measures. Systems thinking to move towards explicit formulation of mental models

most efficient solution over a given period might be highly inequitable. Moreover, beyond simplistic assumptions, more efficient solutions are not necessarily sustainable (Garnett, 2009). There have been efforts towards incorporating equity within health-oriented evaluations, measuring equity impacts or the trade-offs between efficiency and equity (Cookson *et al.*, 2009; Edwards, 2011). The development of 'environmental efficiency' concepts has also led to the inclusion of sustainability goals within efficiency measures (Coelli *et al.*, 2007). Although these methods offer important contributions, it has been suggested that they can incur contradictions with the core theory underlying evaluation (Coast, 2004; Garnett, 2009). For this reason, some authors suggest caution in using or interpreting these adapted CEA or CBA methods or advocate the use of alternative approaches, as discussed below.

Value changes resulting from interventions

One Health initiatives, like educational or community-building interventions, can affect the values and preferences of the affected actors, increasing their information or their interconnectivity with actors in other parts of the system. Neoclassical economics assumes that preferences are fixed and intrinsic to the individual, making it impossible to incorporate changing values into economic assessments (Jan, 1998).

Valuing multiple health and non-health outcomes

Both health and non-health impacts are key to One Health initiatives. However, the outcome measures used in both cost–utility and cost–benefit evaluations have limitations, particularly in the context of complex evaluations, which still apply to the combined approach described above. First, One Health interventions can have important non-health process outcomes such as empowerment (Smith and Petticrew, 2010; Payne *et al.*, 2013) or education (Weatherly *et al.*, 2009; Edwards, 2011), which are not captured by standard health indices, and which are difficult to monetize. This also applies to other contexts, including certain public health or community interventions (Frew, 2017).

Secondly, CBAs, which are the standard approach when it comes to obtaining a common measure for disparate outcomes, relies on the use of willingness to pay (WTP) to monetize outcomes. Various methods can be used to elicit WTP. Discrete choice experiments or contingent valuation are often used to evaluate health-care interventions or technologies (de Bekker-Grob *et al.*, 2012). This approach involves presenting successive choices between alternatives defined by their attributes, which include cost or price. These choices are used to then infer WTP. Other methods include open-ended questions, auction-style choice experiments, hedonic pricing analysis (Ready *et al.*, 1997) or travel cost methods (Parsons, 2003). The latter two are more commonly used to value environmental public goods. Hedonic pricing is based on the additional market price associated with their proximity to specific environmental public goods. Travel cost, on the other hand, is based on the travelling time (often itself converted to monetary opportunity cost) and economic cost incurred to use a particular environmental service. The WTP measures obtained differ in interpretation, and all have different advantages and limitations which should be carefully considered in context before choosing. Although more widely accepted compared to health, WTP measures in environmental interventions show high variability (Bojke *et al.*, 2018). In general, WTP tends to be dependent on income, potentially skewing resources towards interventions valued by higher income individuals.

In order to address these limitations, the literature on health-related interventions with multiple outcomes has suggested the use of cost-consequence analysis (CCA) (Coast, 2004), where a range of costs and consequences of different options are presented, often in the form of a table, to allow for explicit comparison. Others have suggested the development of capabilities-orientated evaluation (Coast *et al.*, 2008; Lorgelly *et al.*, 2010; Greco *et al.*, 2016) based on the political philosophy developed by Sen (1980) and Nussbaum (2003). The latter can be particularly relevant in cases where there are non-market, non-health outcomes which are important to human well-being. While use of a capabilities framework involves a considerable theoretical departure from the traditional framework of economic evaluation (Coast *et al.*, 2008), CCA can be thought of as a pragmatic and flexible approximation to evaluation, which involves a recognition of the limitations of more sophisticated CUA and CBA approaches. CCA does not preclude monetization of specific outcomes, and can be used in combination with methodologies such as multi-criteria decision analysis (Baltussen and Niessen, 2006; Huang *et al.*, 2011; Cinelli *et al.*, 2014). These methods are aimed at weighting and prioritizing multiple outcomes to facilitate structured and transparent decision making and can be of use in the context of One Health interventions.

Complex Systems Analysis for the Economic Analysis and Evaluation of One Health

Assessing population-level and system-level interventions

One Health initiatives are generally aimed at the population or ecosystem level. As such, they have relevant outcomes that pertain to the system as a whole, such as stability, equity or stewardship (Rüegg *et al.*, 2017). This can be understood as 'emergent properties' of a complex system. Traditional economic evaluation tends to focus on the individual as the unit of analysis and sum up to obtain an aggregate effect (Payne *et al.*, 2013). This approach not only misses emergent system properties but can also lead to misleading results even at the individual level by failing to account for individual feedback effects happening at the macro level (Smith and Petticrew, 2010).

Macro or system dynamics methods recommended for dealing with complexity can also address the issues of aggregation, emergent properties and feedbacks that arise when considering interventions at the population or system level. The inclusion of intermediate outcome measures at different points in the system has also been advocated in this regard (Smith and Petticrew, 2010). The issue of outcome measures will be discussed in more detail further on in this section.

Complex systems analysis

Systems analysis or complex systems analysis refers to a variety of methods to analyse systems characterized by strongly non-linear dynamics, feedback loops and emergent system properties. Many of these methods can be applied to the context of One Health initiatives (Canali *et al.*, 2018).

This includes some predominantly qualitative methods such as the social-ecological systems framework (Ostrom, 2009). Other qualitative frameworks for systems analysis are often not explicitly framed within complexity science, but share many of the core assumptions, including value chain analysis or certain frameworks based on institutional economics (Jan, 1998).

Other methodologies have a quantitative component, such as network analysis, compartmental models, agent-based modelling, system dynamics and bio-economic modelling (Canali *et al.*, 2018). These models, however, are still frequently developed and presented using a mixed-methods approach, often starting with more qualitative or narrative descriptions of the system, which can then be formalized and stylized into graphical and mathematical models (Lie *et al.*, 2017).

In particular, system dynamics is increasingly established as a mixed-methods approach, and increasingly formalized and sophisticated processes are being developed for the translation of qualitative narrative information into formalized models (Siokou *et al.*, 2014).

Complex systems analysis methods can contribute to the economic evaluation of One Health in the following way:

1. *Explicit communication of mental models, assumptions and system boundaries:* The use of systems analysis frameworks can be a useful tool for communicating underlying mental models, assumptions about how the intervention works, the perspective being adopted and the implicit boundaries of the system (Peters, 2014).
2. *Attribution of costs and impacts:* Systems modelling can support the correct attribution of impacts and costs across multiple stakeholders and across time periods in cases where simplistic linear analysis might lead to misleading estimates.
3. *Identification of relevant intermediate outcome measures:* An explicit formulation of the mechanisms by which the intervention works can also help identify relevant intermediate outcomes or process measures. These can then be incorporated as evaluation outcomes, potentially in the format of a CCA.
4. *Extrapolation in time or scale:* An explicit analysis of the system incorporating dynamic complexity can be crucial when it comes to extrapolating conclusions to longer time periods or larger scales. This can be true even in cases where a traditional economic evaluation produces reasonable approximations for initial short-term costs and outcomes (Peters, 2014). In some cases, an initial qualitative analysis of the system might suggest whether there are relevant dynamic effects which manifest over time or at larger scales and which might require a full systems analysis (Shiell *et al.*, 2008).

One Health Economics – Where Next?

The application of economic evaluation to One Health challenges across animal and human health sectors and the animal–human interface has shown how this approach can contribute to relevant financial savings and added value and has helped to create momentum. This is important as, globally, the impacts of zoonoses are likely to increase and will continue to threaten humans and the environment.

However, the One Health concept extends beyond zoonosis, and illness in one sector can spill costs over into many other sectors, directly and indirectly. For example, the livestock industry is the backbone of income in many communities, and the impacts of disease have profound economic effects, including loss of agricultural labour force (Lagu *et al*., 2011), loss of key regional agricultural knowledge and defaulting on group savings and credit schemes due to inability to pay for loans (Lengkeek *et al*., 2008). Livestock is also seen as the primary buffer against financial shocks created by HIV/AIDS-related medical expenses for the most disadvantaged (Mutenje *et al*., 2008), showing that economic consequences can spread both from the animal sector to the human one and in the opposite direction.

Further studies are needed to explore bi-directional economic impacts across the animal–human health interface, which will probably contribute to new considerations about investments into disease prevention and control. The global cost of an emerging disease can be far higher than the cost of prevention at its source. Hence a global subsidiary principle, similar to the Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM), is recommended for emerging and possibly also endemic zoonoses (Zinsstag *et al*., 2007). More recent funding instruments, called Development Impact Bonds, share risk between donors and private investors in clearly defined projects that could include zoonosis control (Welburn *et al*., 2016).

Bi-directional economic analysis also implies investigation of the impact of human diseases on animals. Although not yet common, there is literature available about these types of impacts (Lowder *et al*., 2009; Sutherland *et al*., 2011; Thompson, 2013; Bwogi *et al*., 2017; Hlokwe *et al*., 2017; Lagowski *et al*., 2019). Even in situations where humans have been strongly implicated as being a potential risk factor in the spread of diseases to animals (Ferguson *et al*., 2001), follow-up economic evaluation has been mostly non-existent in the scientific literature. It is maybe unlikely that research on the impacts of human-to-animal diseases will receive funding priority in the near future, however, an increased exploration of the effects on the industry is expected, due to the potential economic burden of zoonosis led by humans (e.g. the pandemic spread of *Staphylococcus aureus* in the poultry industry) (Lowder *et al*., 2009). The cost of increasingly stricter biosecurity standards applied in livestock production to minimize the risk of animal infections caused by proximity with humans, reducing the use of antimicrobials and the possibility that resistant bacteria develop in farms (Rojo-Gimeno *et al*., 2016) can also be seen as related examples (see also Szelecsenyi *et al*., Chapter 18, this volume).

Wherever new holistic and integrative frameworks can improve the effectiveness of public health by strengthening the synergies between the multiple disciplines involved in human and veterinary medicine, environmental sciences, ecosystem conservation, natural resource management, farming, and food sciences, there will also be a potential for the economics of One Health. The applications in study fields such as environmental hazards (where the domestic and wild fauna may act as sentinel for contaminations), chronic diseases (where research on animals eases longitudinal investigation on correlations with genetic, environmental and dietary factors), infectious and vector-borne diseases, antimicrobial resistance, and food safety are only a few of the many possible examples (Kahn, 2017) with promising opportunities in the near future.

To fulfil these expectations, One Health economics should expand further into systems thinking and improve its capacity of evaluating health within the complexity of human, animal and environmental interactions. There is a widespread perception that environment is a neglected component of One Health (Essack, 2018; Zinsstag *et al*., 2018) and this could also be said for One Health economics. So far, economic evaluations have mostly focused on human and animal populations, and the budgetary priorities and viewpoints of the health sector's decision makers, somewhat overlooking the assessment of ecosystem relations with health and the consequences on the connected industries and socio-cultural values. A wider holistic approach and the conceptualization of One Health at the systems level considering the three pillars of sustainability (environment, economy and society) simultaneously, will result in a more balanced consideration of both health and non-health impacts in economic evaluations. Inspiration and synergies may also be found in ecological economics, a transdisciplinary field that addresses the linkages between economies and natural ecosystems with a focus on sustainability (Bonaiuti, 2011; Georgescu-Roegen, 1971, 1977, 1979; Jansson *et al*., 1984; Martinez-Alier and Schlupmann, 1990). Central themes are nature, justice, and time combined with questions around intergenerational equity, irreversibility of environmental change, uncertainty of long-term outcomes, and sustainable development (Faber, 2007). Novel conceptualizations of growth and their measurement tools provide an opportunity for different narratives, research and strategies (Melgar-Melgar and Hall, 2020).

Technological advancements allowing for increasing use of Big Data in medical sciences also support this trend with a new 'paradigm shift' that integrates the traditional methods of direct experimentation with a capacity to create new information and knowledge much faster than the usual scientific procedures and to cross multilevel contexts and scales: from molecules, cells and tissues, to individuals, populations and the environment (McCue and McCoy, 2017). This deep innovation in scientific practices and methods is highly promising for improvement of One Health economic analyses to overcome constraints related to scarcity of information and uncertainty, and could be fully capitalized on by incorporating needed computational expertise and enhancing interdisciplinarity working within One Health research groups.

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11 A Legal Framework of One Health: the Human–Animal Relationship

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Introduction

By postulating a closer cooperation of human and veterinary medicine, the One Health concept overtakes the prevailing human–animal differentiation in the law. Corresponding to the historical development of human and animal health into segregated disciplines on academic, governance and application levels, the law does not apply a cohesive understanding. Humans are, as subjects of law, holders of subjective rights and duties. Animals – objects alike – do not have rights; they are subject to the execution of rights ascribed to humans. Animal protection law, which entails health regulations, accordingly addresses humans in their use of animals. The different legal statuses result from the conviction that humans are superior to animals due to their abilities – to speak, to reason and to reflect upon their own existence. However, since the uniqueness of humans is increasingly questioned, the legal treatment of animals has become a highly controversial issue (see for example Francione, 2008; Michel *et al*., 2012; Peters *et al*., 2015; Stucki, 2016; Hild and Schweitzer, 2019; Bunch and Waltner-Toews, Chapter 4, this volume; Lerner and Zinsstag, Chapter 5, this volume; Zinsstag and Tanner, Chapter 32, this volume).

This chapter provides an introduction to the legal framework of One Health. It begins with an overview of national Swiss provisions concerning the human–animal relationship in constitutional law, private law and animal welfare law including animal disease law. The reference to the Swiss norms may also be of service for readers in other civil law systems, as most do not vary substantially regarding the general human–animal relationship; differences exist primarily with regard to the levels of animal welfare. The chapter then introduces European Union (EU) regulations, World Trade Organization (WTO) agreements, World Organisation for Animal Health (OIE) recommendations and World Health Organization (WHO) regulations. Patricia L. Farnese provides a Canadian perspective on human–animal relationship law (Boxes 11.1 and 11.2).

In the conclusion, we submit that greater importance is to be attached to animal welfare issues as part of the One Health concept. The One Health approach is a compelling reason to strengthen animal welfare laws with the purpose of enhancing both animal and, consequently, human health. We propose a juridification of the linkage between human and animal health on a national level as well as regulated cooperation of state institutions for human and animal health and systematized cooperation with international institutions. On an international level, efforts for standardization and faithful implementation of animal welfare law and public health law are to be fostered.

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Box 11.1. A Canadian perspective on human–animal relationship law.

Despite growing influence of the animal rights perspective, humans and animals are also distinguished as subjects and objects in Canadian law.[1] Animals, including wildlife, are primarily treated as property without independent rights. A brief overview of the Canadian legal framework for animals and health demonstrates that human and animal health are primarily regulated separately despite the well-documented links between human and animal health (Farnese, 2014a). Within the legal framework for animal health there is a further separation between the health of animals used in agriculture and wildlife. The health of companion animals or pets gets very little regulatory attention. The enforcement of animal welfare law, however, typically includes companion animals, but in practice often ignores wildlife.

The Canadian Constitution

Animals lack independent, constitutional protection. Animals are regulated by the federal and provincial governments because agriculture and wildlife are areas of shared or overlapping jurisdiction (s.95, 92A, 91(12)).[2] The federal government's criminal law power and jurisdiction to regulate for the 'Peace, Order and good Government' provides additional authority to regulate animals for health, safety and morality purposes. Animals, especially wildlife, may also be regulated pursuant to federal authority over the environment, transboundary issues and federal lands, including national parks and lands reserved for First Nations (s.91(24)).

The provinces further rely on their exclusive jurisdiction over public lands, local works and undertakings, property and civil rights, and matters of a local private nature to regulate animal health and welfare (s.91(5), (10), (13), (16)). In addition, municipalities rely on delegation of authority from provinces to pass bylaws related to animal health and welfare (s.91(8)).

National Regulations

The human–animal relationship is regulated in constitutional law, private law and animal welfare law. Similar to most legal systems, Swiss constitutional law is superior to any other law and codifies the national state organization, defines national state objectives and guarantees fundamental human rights. Constitutional law hence carries great authority and indicates social values and policies. In the words of Wagman and Liebman (2011), 'a constitution sets down basic parameters for the ordering of the daily lives of a governing body's citizens; [it is] a sort of template for common behaviours'. The constitution principally defines the legal relationship between the state and its citizens; it does not – due to its character as a general legal framework – provide meticulous rules concerning the human–animal relationship, but rather establishes fundamental positions. In contrast, private law regulations govern the legal relationship between citizens among one another, as they, for example, sell and buy animals. Animal welfare law restrains the public law on the basis of the constitution, dealing with the handling of animals, their keeping and their use.

Constitutional law

The constitution is written from an anthropocentric perspective: the human person stands in the centre of all legal relations and has subjective rights. The non-human animal does not have rights; it is merely granted legal protection. Animal protection addresses both animals as species and the individual animal. As a Swiss particularity, the constitution protects the dignity of the creature. Four articles affect the human–animal relationship: Articles 78, 79, 80 and 120 Bundesverfassung (BV).

Article 78 BV (Protection of natural and cultural heritage) and Article 79 BV (Fishing and hunting) protect animals as species. Article 78 (4) BV states: 'It [the responsible canton] shall legislate on the protection of animal and plant life and on the preservation of their natural habitats and their diversity. It shall protect endangered species from extinction.'[3] In contrast, Article 80 BV (Protection of animals) protects the individual animal (Marti, 2014) and demands to legislate on the protection of animals regarding the keeping and care, experiments, use, import, trade, transport and slaughter. The norm awards the individual animal protection with a constitutional status, meaning that it must be taken into consideration within the entire regulation system (Federal Supreme Court, 2009).

Article 120 (2) BV (Non-human gene technology) additionally protects the dignity of the creature. It is to be noted that Switzerland was the first, and remains the only, state to insert this new subject of

Box 11.2. A Canadian perspective.

Animal Health

Briefly, animal health regulations create reporting obligations on persons, including non-owners, in control of an animal that is known or suspected of having a listed disease. Public health and veterinary officers also have the power to investigate disease threats and to respond to these threats. These actions can be ordered for infected animals or as a preventative measure. The Canadian Food Inspection Agency (CFIA) or the Agriculture and Agri-Food Canada (AAFC) lead these actions at the federal level. Similar authority to act can be found in equivalent provincial departments (Farnese and von Tigerstrom, 2008).

Animal health regulations primarily target animals used in agriculture, and it is only when a wildlife disease is known to have human impacts, either by being zoonotic or harmful to farm animals, that wildlife health becomes a subject of regulation. Instead, wildlife regulations focus on use and access to wildlife as a resource. Consistent with the common law, provincial legislation designates all wildlife as property of the province until it is lawfully captured. Therefore, most provincial wildlife laws focus on licensing programmes that permit individuals to legally acquire rights in wildlife through hunting, fishing and trapping. Wildlife is treated as a resource that is available for use, but in need of management to ensure continued supply (Farnese, 2014a).

Animal Welfare

In Canada, it is a criminal offence to intentionally cause unnecessary pain, suffering or injury to animals (Criminal Code, RSC (1985), c. C-46, s.445(1)-s.445.1(1)). These offences fall under the section of the criminal law dealing with crimes to property thereby reinforcing the status of animals as incapable of holding independent rights. These criminal code sections have remained substantively unchanged since they were first introduced at the turn of the 20th century. Repeated attempts to modernize these sections have been successfully opposed by the agriculture sector, who feel they will be unfairly targeted by any reforms.

The Health of Animals Act and the Safe Food for Canadians Act contain federal regulatory offences related to the humane treatment, transport and handling of animals used in agricultural production. These regulatory offences are absolute liability offences with virtually no defence available to the accused. Voluntary industry standards play an important role in regulatory enforcement because they outline generally accepted management practices. The further one's conduct is from these standards, the more likely the conduct will be perceived as a violation. In many ways, the regulatory offences are a more effective animal welfare tool. The burden of proof for regulatory offences is on a balance of probabilities rather than beyond a reasonable doubt. Conviction for a regulatory offence also does not require proof of intent.

Provinces also use regulatory offences to enforce animal welfare standards. Each jurisdiction has a slightly different definition of 'animal' thereby creating slight variations in the application of animal welfare laws across the country. None the less, provincial laws generally make it an offence to cause 'distress' to animals, which will include companion animals and animals used in agriculture. They also establish duties of care for people who own or care for animals. Like the federal regulatory offence, industry standards play an important role in enforcement (Fraser *et al*., 2018). Most provinces exempt those who follow generally accepted management practices in the industry from prosecution.

Conclusion

The motive underlying most regulations related to animals is minimizing negative human impacts, including economic, health and cultural impacts. The separation of human and animals in law, especially as related to health, however, places human health at risk (Farnese, 2014b). The One Health concept offers a critical lens from which to reassess the consequences of a human–animal divide in law.

Legislation

Constitution Act, 1867 30 & 31 Victoria, c. 3 (UK).
Criminal Code, RSC 1985, c. C-46.
Ending the Captivity of Whales and Dolphins Act, S.C. 2019, c. 11.
Health of Animals Act, S.C. 1990, c. 21.
Safe Food for Canadians Act, S.C. 2012, c. 24.

protection into the constitution. The term 'dignity of the creature' is not defined within the constitution. Scholars and the government understand the term as the acknowledgement of the existence of an inherent value of the individual animal (Goetschel, 2002; Richter, 2007; Schweizer, 2014; Federal Office for Food Safety and Veterinary Affairs, 2020). Although an analogy seems apparent at first sight, the legal term 'dignity of the creature' is not be equated with the legal term 'human dignity' (Errass, 2013). The inherent dignity of human beings, as for instance referred to in the preamble to the United Nations Declaration on Human Rights, is understood to be inherent to all human beings and cannot be lost or acquired. In contrast, the dignity of the creature merely establishes a legally protected position within the balancing procedure (Schweizer, 2014; Federal Office for Food Safety and Veterinary Affairs, 2020). Animals shall only be made of use insofar as that usage can be justified with outweighing legitimate (human) interests (Mastronardi, 2014). None the less, several authors argue that the dignity of the creature has an impact on other articles of the constitution and that it relativizes the anthropocentric viewpoint of the law (Errass, 2013; Schweizer, 2014).

Private law

Unlike constitutional law, the private law governs the legal relations of the citizens with one another. It distinguishes between subjects of law and objects of law. Subjects of law are natural persons and legal entities. The latter, also called legal persons, denote corporate bodies governed by private law, for example joint-stock or limited liability companies. As subjects of law, these legal and natural persons are holders of subjective rights and duties (Article 11 (2), Article 53 Schweizerisches Zivilgesetzbuch, ZGB).

In contrast, objects of law are so-called things, which persons can claim to have rights over. Objects of law are generally subordinated to the power of disposition of the owner (Article 641 (1) ZGB). Until 2003, animals were assigned to the category of objects of law under the Swiss Civil Code. This absolute-object status stood in stark contrast to the constitutional protection of the dignity of the creature, which was implemented in 1992. Furthermore, the classification of animals as things was seen as outdated pursuant to the public opinion (Kommission für Rechtsfragen des Ständerats, 2002; Goetschel and Bolliger, 2003). Accordingly, the Federal Supreme Court argued in 1989 that the general attitude of humans towards animals has changed with time to an 'ethical animal welfare', which respects the animal as a living and feeling creature (Federal Supreme Court, 1989). Since 2003, the Swiss Civil Code (Article 641a (1) ZGB) states explicitly that animals are not things. The bisection of persons and things was altered into a trisection of natural and legal persons, things and animals. Consequently, the inserted regulation has not brought the categories of animals and humans closer together in the sense of the One Health concept, but rather created a further category. Under Article 641a (2) ZGB, animals are now treated generally analogous to things. In short, animals are no longer treated as things, but rather like things (Wiegand, 2011).

Animal welfare law and animal disease law

The general right to use animals is restricted by animal welfare law, which provides norms for the use of animals. These regulations are enacted on the grounds of the constitution. As most European animal welfare laws, Swiss law is based on the concept of ethical animal protection, which safeguards the animal for its own sake. Because the animal is respected as a living and sentient fellow creature, its needs set the reference for legal protection (Michel, 2012; Errass, 2013). However, in compliance with the constitution, animal welfare law does not establish subjective rights for animals, but sets rules of conduct for humans. Animal welfare law stands in a field of stark tension between human beneficiary and animal protection interests. As a consequence, animal welfare constitutes a mere legal position that is to be considered within the specific balancing of legally protected interests (Michel, 2012).

In Switzerland, animal welfare is regulated by both the Animal Welfare Law (Tierschutzgesetz, TSchG) and the Animal Welfare Order (Tierschutzverordnung, TSchVO). Animal welfare norms govern the handling of animals, their keeping and their usage and intrusions by humans (Article 1 TSchV). Animal welfare law is primarily applicable to vertebrates. Invertebrates are only protected where the Federal Council explicitly ordered an application of the animal welfare law due to scientific results concerning the capacity of sensitivity of the species (Article 2 (1) TSchG).

Article 1 TSchG sets out the purpose of protecting the dignity and the well-being of the animal. Whereas the constitution does not provide any definition, the term 'dignity of the creature' is further defined within the animal welfare law. Pursuant to Article 3 lit. a TSchG, dignity defines the intrinsic value of the animal that has to be respected. The dignity of the animal is injured when an intrusion of the animal cannot be justified with outweighing legitimate interests. An intrusion is especially given when the animal suffers pain, fear, damages, humiliation, its appearance is decisively altered, its physical abilities are decisively disturbed or it suffers excessive exploitation. Well-being is considered to be given when the following occur: (i) the keeping and feeding of the animal does not disturb its bodily functions and behaviour in a way to which the animal cannot adapt; (ii) the usual species behaviour within its biological capacity of adaptation is possible; and (iii) the animals are of clinical health, and pain, suffering and damages are avoided (Article 3 lit. b TSchG). Pursuant to Article 4 (1) TSchG, everyone who uses and handles animals must take account of their needs as best as possible and must care for their well-being as far as the purpose of the intended usage allows to do so.

The link between animal welfare, animal health and consequently human health is not explicitly recognized in animal welfare law. It is only clearly adhered to in animal disease law, meaning the Animal Diseases Act (Tierseuchengesetz, TSG) and the Animal Diseases Ordinance (Tierseuchenverordnung, TSV). The TSV identifies various highly contagious and other diseases and lays down control measures (Article 1). According to the TSG, highly contagious diseases are to be eradicated as quickly as possible or otherwise controlled like other diseases. Other diseases will be eradicated if there is a health or economic need and if the objective can be achieved at a reasonable cost; otherwise they are to be controlled or monitored (Article 1a).

In general, animal health monitoring is based on five pillars: (i) a reporting obligation; (ii) a monitoring programme; (iii) examination of animal defecation sites; (iv) import controls; and (v) meat inspection (Federal Office for Food Safety and Veterinary Affairs, 2020). The obligation to notify obliges all persons who keep, care for or treat animals to report outbreaks of animal diseases or suspicious observations to a veterinarian (Article 61 TSV, Article 1 TSG). The obligation to report also applies to bees, fish and wildlife. Disease-specific screening programmes are coordinated by the federation and the cantons. The development and spread of antibiotic-resistant bacteria is also monitored by a specific programme. Information on all outbreaks of notifiable diseases in Switzerland can be viewed in a provided database (Information System for Disease Notifications), where it can be queried according to various criteria (Federal Office for Food Safety and Veterinary Affairs, 2020).

International Regulations and Organizations

Apart from exceptions within the EU, an international animal welfare and health standard to judge legislative efforts within one country does not exist. Some countries have adopted provisions strengthening animal welfare, others have enacted welfare laws but lack enforcement resources or political will to enforce their laws and still others have not expressed an interest in animal welfare at all (Favre, 2012; Global Animal Law, 2020). None the less, international efforts for standardization are progressing and many participants of international agreements accept the governance of a central institution entitled to control actions of the agreement's member countries and respectively that of their citizens.

European regulations

European recommendations and regulations have been developed within both the Council of Europe (COE) and the EU since 1974. The EU legislation is one of the most advanced worldwide (Simonin and Gavinelli, 2019). Within the EU, competence was originally limited to fields where national regulations on animal welfare touched economic issues of the common market. For this reason, issues of pet and wild animal treatment were reserved for national member states to decide. Regarding farm animals that influence the common market, the EU enacted several directives and regulations with set requirements for housing and treatment. It was only in 2009 that animal welfare became a contract objective of the EU.

The COE has adopted the following binding conventions to control the use of animals:[4]

- European Convention for the protection of animals kept for farming purposes, ETS No. 87, March 1976 and the Protocol of Amendment to the European Convention for the Protection of Animals kept for farming purposes, ETS No. 145, February 1992;
- European Convention for the protection of animals for slaughter, ETS No. 102, May 1979;

- European Convention for conservation of European wildlife and natural habitats, ETS No. 104, September 1979;
- European Convention for the protection of vertebrate animals used for experimental and other scientific purposes, ETS No. 123, March 1986 and the Protocol of Amendment to the European Convention for the protection of vertebrate animals used for experimental and other scientific purposes, ETS No. 170, June 1998;
- European Convention for the protection of pet animals, ETS No. 125, November 1987; and
- Revised European Convention for the protection of animals during international transport, ETS No. 193, November 2003.

The most relevant EU directives and decisions are:[5]

- Council Directive 98/58/EC, July 1998, concerning the protection of animals kept for farming purposes;
- Council Directive 1999/74/EC, July 1999, concerning minimum standards for the protection of laying hens;
- Council Regulation No. 1/2005 EC, December 2004, concerning the protection of animals during transport and related operations;
- Council Directive 2007/43, June 2007, concerning minimum rules for the protection of chickens kept for meat production;
- Council Directive 2008/119/EC, December 2008, concerning minimum standards for the protection of calves;
- Council Directive 2008/120/EC, December 2008, concerning minimum standards for the protection of pigs;
- Council Regulation No. 1099/2009 EC, September 2009, concerning the protection of animals at the time of killing; and
- Directive 2010/63/EU of the European Parliament and of the Council, September 2010, concerning the protection of animals used for scientific purposes.

Since the enactment of the Treaty of Lisbon in 2009, the EU member states explicitly recognize that animals are sentient beings and they commit to thorough animal protection. Article 13 of the Treaty on the Functioning of the EU accordingly states:

> In formulating and implementing the Union's agriculture, fisheries, transport, internal market, research and technological development and space policies, the Union and the Member States shall, since animals are sentient beings, pay full regard to the welfare requirements of animals, while respecting the legislative or administrative provisions and customs of the Member States relating in particular to religious rites, cultural traditions and regional heritage.

WTO regulations and recommendations

In 1995 the WTO was founded as a successor to the General Agreement on Tariffs and Trade (GATT), which was founded with the purpose of encouraging trade liberalization and international economic cooperation. The WTO counts 164 member states today. Since the member states treat animals legally as or like property, the GATT regulations apply to any international trade involving animals or animal products.

The free-trade-oriented GATT rules have long been criticized to limit the member states in their rights to restrict imported goods on grounds of animal welfare (Hunter *et al*., 1998; Kelch, 2011; Wagman and Liebman, 2011): Article I GATT prohibits discrimination of 'like' product from different countries. It remains under discussion whether a trade restriction is admissible if the levels of animal welfare applied during the breeding, keeping and killing of the animal differ. This dilemma can be illustrated by cases brought before the WTO Tribunal that held a member country's measures to protect threatened species violated the WTO regulations (Tuna-Dolphin Case I, 3 September 1991; Tuna-Dolphin Case II, 16 June 1994; Shrimp-Turtle Case I, 12 October 1998; Shrimp-Turtle Case II, 22 October 2001). However, in 2013 the WTO Tribunal ruled for the first time that animal welfare could be a sufficient reason for a trade ban (WT/DS400/R/Add.1; WT/DS401/R/Add.1). This decision indicated a change in the jurisprudence of the WTO Tribunal on animal welfare issues (Wettlaufer, 2017). It was based on Article XX GATT, which lays out several instances in which WTO member states may be exempted from GATT principles for free trade: a WTO member country may enact measures that are 'necessary to protect public morals' (lit. a), 'necessary to protect human, animal or plant life or health' (lit. b) or that relate 'to the conservation of exhaustible natural resources if such measures are made effective in conjunction with restrictions on domestic production or consumption' (lit. g). Thereby, rules must not be applied as a means of 'arbitrary or unjustifiable discrimination between countries where the same conditions prevail' and must not be 'a disguised restriction on international trade'. Still, member states must provide conclusive proof that the taken measures fall under the GATT exceptions.

Further, under the Agreement on the Application of Sanitary and Phytosanitary Measures, the WTO members are bound to the standards for animal health established by the OIE. The OIE is the direct successor of the Office International des Epizooties, founded in 1924 to fight animal diseases at a global level. The OIE is a reference organization to the WTO with a total of 182 member states. The organization is under the authority and control of the World Assembly of Delegates consisting of delegates designated by the governments of all member states. Under the Agreement on the Application of Sanitary and Phytosanitary Measures, which entered into force with the establishment of the WTO in 1995, the OIE is charged with creating standards for animal health. The OIE Sixth Strategic Plan (2016–2020) perpetuates scientifically based standards and guidelines for animal health, animal welfare, animal production and food safety and explicitly recognizes the One Health approach for the reduction of risks of high impact diseases at the animal–human–ecosystems interface. The three strategic objectives include:

- ensuring the health and well-being of animals and the safety of animal-based food and products, and reduce the transmission of diseases, notably by controlling the risks at the human–animal–environment interface;
- establishing trust between stakeholders and trading partners in cross-border trade of animals and animal-based products and foods, through transparency and good communication on the incidence of epidemiologically important diseases, and through the OIE standards on the sanitary safety of exchanges; and
- strengthening the capacity and sustainability of national veterinary services (OIE, 2015).

The Terrestrial Animal Health Code of the OIE, which was adopted in its 28th edition by the World Assembly of Delegates of the OIE in May 2019, provide standards for the improvement of animal health and welfare and veterinary public health worldwide, including standards for international trade in mammals, reptiles, birds and bees and their products. The health measures in the Terrestrial Animal Health Code are supposed to be used by national veterinary authorities to provide for early detection, reporting and control of agents that are pathogenic to animals or humans, and to prevent their transfer via international trade in animals and animal products, while avoiding unjustified sanitary barriers to trade (OIE, 2020a). All of the provisions are phrased as recommendations. Article 7.1.2 (1–8) provides the following guiding principles for animal welfare, which also factor the interrelationships of the One Health concept.[6] Further, OIE member countries are invited to report on the performance of veterinary services (PVS), including efforts towards institutionalizing One Health, on a voluntary basis (OIE, 2020b).

1. That there is a critical relationship between animal health and animal welfare.
2. That the internationally recognized 'five freedoms' (freedom from hunger, thirst and malnutrition; freedom from fear and distress; freedom from physical and thermal discomfort; freedom from pain, injury and disease; and freedom to express normal patterns of behaviour) provide valuable guidance in animal welfare.
3. That the internationally recognized 'three Rs' (reduction in numbers of animals, refinement of experimental methods and replacement of animals with non-animal techniques) provide valuable guidance for the use of animals in science.
4. That the scientific assessment of animal welfare involves diverse elements which need to be considered together, and that selecting and weighing these elements often involves value-based assumptions which should be made as explicit as possible.
5. That the use of animals in agriculture, education and research, and for companionship, recreation and entertainment, makes a major contribution to the well-being of people.
6. That the use of animals carries with it an ethical responsibility to ensure the welfare of such animals to the greatest extent practicable.
7. That improvement in farm animal welfare can often improve productivity and food safety, and hence lead to economic benefits.
8. That equivalent outcome based on performance criteria, rather than identical systems based on design criteria, be the basis for comparison of animal welfare standards and recommendations.

WHO regulations

A central responsibility of the WHO is the management of a global regime for control of the international spread of disease. The International Health Regulations (IHR) of the WHO were drafted to meet this purpose and were first adopted by the Health Assembly in 1969. Because the IHR were considered non-responsive to the major challenges of emerging infectious diseases and bioterrorism, the WHO engaged in a process to modernize the IHR (Gostin, 2004). As a result, the IHR 2005 were adopted by the World Health Assembly and entered into force as a legally binding agreement with currently 196 member states (WHO, 2020).

Among other improvements, the IHR now contain a scope not limited to any specific disease or manner of transmission. They state party obligations to develop certain minimum core public health capacities in disease surveillance and response, party obligations to notify the WHO of events that may constitute a public health emergency according to defined criteria and provisions authorizing the WHO to take unofficial reports into consideration. Animals are included in the scope of application of the IHR. For instance, 'contamination' is defined as the presence of an infectious or toxic agent or matter on a human or animal body surface, 'goods' mean tangible products, including animals and plants, and 'infection' means the entry and development or multiplication of an infectious agent in the body of humans and animals (Article 1 IHR). Pursuant to Article 22 (1) lit. e IHR, the competent authorities shall be responsible for the supervision of the removal and safe disposal of any contaminated water or food and human or animal dejecta. Further, for responding to events that may constitute a public health emergency of international concern, designated airports, ports and ground crossings must provide assessment of and care for affected travellers or animals, by establishing arrangements with local medical and veterinary facilities for their isolation, treatment and other support services (Annex 1. B. 2. lit. b).

The IHR 2005 provide a remarkable legal framework to promote international public health. A unique aspect is the collective commitment requiring intersectoral cooperation between the WTO and the state parties, as well as within the states themselves, which includes cooperation among different administrative or governmental levels, and horizontally across ministries and disciplines (Rodier *et al.*, 2006). Due to a lack of implementation of the IHR in several member countries, the Global Health Security Agenda (GHSA) was launched as a partnership between nations and international organizations including the WHO, OIE and the Food and Agricultural Organization of the United Nations (FAO) in 2014. The prevention of zoonotic diseases is now one of the focus areas of the GHSA. Within 5 years, target countries are supposed to have adopted measured behaviours, policies and practices to minimize the spillover of zoonotic diseases into human populations. Thereby, the One Health approach is emphasized across all relevant sectors of the respective governments (Meier *et al.*, 2017; Phelan and Gostin, 2017).

Prospects

The One Health approach is a compelling reason to enact further animal welfare legislation as strengthened animal welfare laws will improve animal health and successively also lead to enhanced human health. Initial thoughts on a legal implementation of the One Health approach lead to the following considerations.

On a national level, a juridification of the One Health concept would require the explicit recognition of the correlation of human and animal health in the law; animal disease law on its own is insufficient to meet the general approach of the One Health concept. We advocate for a legal basis for a close cooperation of human and veterinary medicine on the grounds of higher animal welfare. Further, type and scope of stronger regulated cooperation of institutions for human and animal health need to be implemented. Also, stronger regulated cooperation with international institutions and other states need to be realized.

On an international level, animal welfare law needs to be expanded and faithfully implemented. Excluding exceptions in the EU, no binding and faithfully enforced agreement exists that ensures the welfare of animals, nor is there any international standard that regulates and defines acceptable treatment. The consequence is diverse standards regarding animal protection – and consequently, animal health. Health threats cannot be ameliorated by states acting on their own. Present global health challenges instead require a multisectoral approach in which health is a fundamental value within global governance and international law. Existing international efforts for standardization of animal welfare law and international public health law, such as the EU legislation, the IHR and recommendations of the OIE are to be fostered and extended. Private initiatives like Global Animal Law[7] further contribute to foster the development of animal protection laws worldwide.

Notes

[1] Evidence of this growing acceptance can be found in the Chief Justice Fraser of the Alberta's Court of Appeal's dissenting decision in Reece v The City of Edmonton (2011) 2011 ABCA 238 that addressed the ongoing captivity of Lucy, an Asian elephant. More recently, the Ending the Captivity of Whales and Dolphins Act 2019 S.C., c. 11 was passed by the federal government which makes it a criminal offence to hold cetaceans in captivity.

[2] All sections referred to in Box 12.1 refer to this legislation: Constitution Act, 1867 (UK), 30 & 31 Vict, c 3, reprinted in RSC 1985, App II, No 5. Canada Act 1982 (UK), c 11.

[3] All translations of the Swiss legal texts are taken from the official website of the Federal Authorities of the Swiss Confederation: http://www.admin.ch (accessed 9 January 2020).

[4] All texts can be found at: http://coe.int/t/e/legal_affairs/legal_cooperation/biological_safety_and_use_of_animals/Conventions.asp (accessed 9 January 2020).

[5] All texts can be found at: http://ec.europa.eu/food/animal/welfare/references_en.htm (accessed 9 January 2020).

[6] World Organisation for Animal Health (2020) Terrestrial Animal Health Code. Available at: https://www.oie.int/standard-setting/terrestrial-code/ (accessed 9 January 2020).

[7] Global Animal Law.org – Available at: www.globalanimallaw.org (accessed 16 February 2020).

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12 Animal–Human Transmission Models

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Introduction

More than 60% of human infectious diseases are caused by pathogens shared with animals (Karesh *et al*., 2012). While there is a large body of knowledge of intraspecies transmission of infectious disease, we know surprisingly little about the dynamics of between-species transmission of zoonotic pathogens (Lloyd-Smith *et al*., 2009). Yet, to understand the animal–human interface, assess the best interventions and make cross-sector economic analyses of the cost of zoonoses, it is critical to understand the animal–human transmission dynamics. Understanding animal–human transmission of disease is difficult because it requires an understanding of animal and human ecological and demographic processes as well as the pathogens that circulate between them. This is a prime One Health topic as it not only involves human and veterinary medicine but also ecology, agriculture, microbiology and the social sciences. Understanding One Health as the added value of closer cooperation between human and animal health, animal–human transmission models are at the heart of assessing the animal–human interface. They are a necessary requirement for the comparative analyses of the profitability and cost-effectiveness of interventions in humans, animals and the environment. The primary purpose of this chapter is to provide examples of animal–human transmission models of zoonotic diseases in view of cross-sector economic analyses (Häsler *et al*., Chapter 10, this volume).

Understanding of the ecology of the transmission of zoonoses between animals and humans is a fundamental requirement on the way towards their efficient control and elimination. Often the human medical sector concentrates on clinical issues of rabies or brucellosis patients and does not address the diseases at their roots, which would lead towards primary prevention of transmission, avoiding future human cases (Madkour, 2001; Diop *et al*., 2007; Rattanavipapong *et al*., 2019). From the perspective of disease ecology, such an approach ignores at which level the transmission of a zoonosis could successfully be interrupted. Towards this end, we mention here the well-known concept of the basic reproductive number. The basic reproductive number (R_0) is defined as the expected number of secondary infections produced when one infected individual is introduced into a host population in which every host is susceptible. The R_0 describes the potential of spread of an infectious disease and its regulation in a host population. If R_0 is above 1 the disease keeps spreading; if R_0 is below 1 the disease will go extinct. In the course of an epidemic, the effective reproductive number, R_e, reflects the number of secondary infections produced at a given moment after the onset of the epidemic with no assumption of a fully susceptible host population. Zoonoses feature inter- and intraspecies transmission pathways; consequently inter- and intraspecific R_0 can be estimated (Zinsstag and Tanner, Chapter 32, this volume).

We can distinguish three main types of zoonoses, according to their transmissibility in humans: (i) diseases like brucellosis and rabies, which are transmitted to humans from animals without human-to-human transmission – in this category R_0 is > 1 in animals and < 1 in humans; (ii) pathogens that spill over into populations with limited human-to-human transmission (e.g. monkeypox) – R_0 in humans is close to 1 and may lead to 'stuttering transmission'; and (iii) diseases like influenza that persist in animal

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reservoirs but once transmitted to humans may cause persistent and even epidemic transmission in humans with $R_0 > 1$ (Lloyd-Smith *et al.*, 2009). Such a transmission pathway from live animal markets to humans is suspected in the COVID-19 respiratory disease outbreak in Wuhan, China (Hui *et al.*, 2020). There is additionally a fourth category of anthroponotic diseases where $R_0 > 1$ in humans and < 1 in animals, such as human malaria.

In this chapter we primarily focus on diseases of the first categories (i.e. without human-to-human transmission or with limited human-to-human transmission), which clearly require an intervention in the animal reservoir and in food safety or improved sanitation in order to interrupt transmission to humans.

Zoonotic diseases can also be characterized by their route of transmission: (i) direct animal–human transmission; (ii) vector-borne transmission; and (iii) environmental (waterborne, soilborne, foodborne) transmission. Although some diseases exhibit multiple modes of transmission and the relative importance of each is commonly unknown, there is often still a primary mode (see *Opisthorchis viverrini* transmission, Fig. 12.1). Additionally, non-reservoir hosts may play an important role in transmission dynamics (e.g. zoophagic malaria vectors biting frequently non-human hosts exhibit a lower risk of human-to-human infection).

Mathematical transmission models are simplified and abstracted representations of transmission processes of infectious diseases, as described in detail

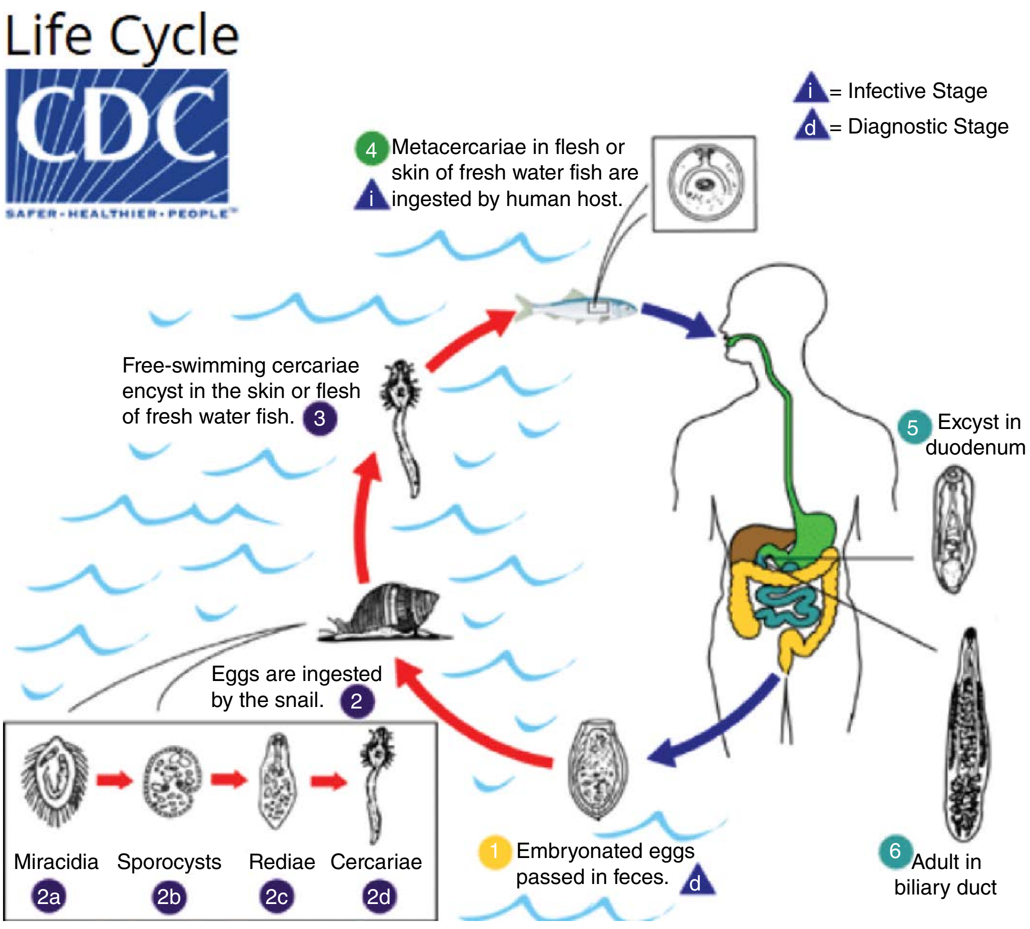

Fig. 12.1. Schematic life cycle for *Opisthorchis viverrini* and *Opisthorchis felineus*. From Centers for Disease Control and Prevention, 2018, reproduced with permission.

in many textbooks (Anderson and May, 1991; Keeling and Rohani 2008; Diekmann *et al*., 2013). Mathematical models can generally be classified as deterministic (which assumes that the system always follows a fixed rule with no randomness or chance) or stochastic (where randomness is present and one state may lead to multiple different states). Deterministic models are easier to analyse, and provide general statements that improve our understanding of disease dynamics. Stochastic models are difficult to analyse but provide more information away from the mean behaviour of the system, such as the effects or occurrence of low probability events.

Furthermore, models are either population-based (where populations or subsets of populations are treated homogeneously) or individual-based (where each individual human or animal is treated separately). Population-based models can either be deterministic or stochastic but are often deterministic. Individual-based models are almost always stochastic. Population-based models can be further classified as prevalence models (suitable for microparasites where the state variables are the proportions of hosts in different disease categories such as susceptible, infected, asymptomatic or immune) or burden models (suitable for macroparasites where the state variables are usually the mean number of different stages of the parasite per host).

Most deterministic population-based models are based on the seminal work of Kermack and McKendrick (1927) that divided the human population into susceptible, infected and recovered classes, and assumed mass action dynamics for their interaction and the transmission of disease. These models have formed the basis of much of mathematical epidemiology and led to many insights in the understanding and control of infectious diseases like the above-mentioned R_0. Newer stochastic individual-based models have further improved our understanding and are better suited to simultaneously include different kinds of heterogeneity and to capture more detailed aspects of disease transmission and control. However, they are computationally more intensive and require more detailed data for their calibration. Such data are not always available, and we must strike a balance between model detail and the scarcity of data.

The most appropriate model is the most parsimonious one that answers the question posed, and not the most detailed. Models will always be representations which abstract a constructed reality with a certain level of imprecision and are most useful if they have a clear purpose. For this reason, it is important to state the purpose of the model prior to its development. We begin writing animal–human transmission models because we want to answer practical questions like: 'Is it cost-beneficial to mass vaccinate cattle, sheep and goats to prevent human brucellosis?' or 'Should we mass vaccinate dogs against rabies or rely on human post-exposure prophylaxis in an African city'? Based on these practical questions, the purpose of the animal–human transmission models presented in this chapter is to relate human disease frequency to the animal reservoir, providing a mechanism for the comparison of the effectiveness of interventions in humans and animals.

Directly Transmitted Zoonoses

In their textbook on modelling of infectious diseases, Keeling and Rohani (2008) emphasize the importance of animal–human transmission models of directly transmitted zoonoses for decisions on public health-related action. They criticize the scarcity of such models and present a generic framework for animal–human zoonoses transmission. Since cross-species transmission is the main characteristic of zoonoses, an ecological understanding involving all related hosts is of particular importance for understanding the occurrence in humans (Keeling and Rohani, 2008). The force of human infection depends on the prevalence in the animal reservoir, the rate of human–animal contacts and the probability of infection per contact. The frequency, duration and quality of the contact are different in zoonoses transmitted by wildlife, domestic animals or pets (Lloyd-Smith *et al*., 2009). Methods have been developed for the simultaneous assessment of human and animal zoonosis seroprevalence, allowing for the identification of the main source of transmission (Schelling *et al*., 2003; Bonfoh *et al*., 2011). Time series of such data are the most suitable for estimating animal–human transmission model parameters (Kayali *et al*., 2003a). A detailed description of such One Health study designs is presented in Schelling and Hattendorf (Chapter 8, this volume).

Brucellosis

Brucellosis re-emerged as a preventable public health problem in the post-socialist years in Mongolia after 1990 (Schelling *et al*., Chapter 20, this volume). International experts recommended that Mongolia reinstate livestock mass vaccination to prevent human brucellosis. At this stage, the World Health Organization (WHO) asked if brucellosis mass vaccination was cost-beneficial for the prevention of human brucellosis in Mongolia. For the purpose of a cross-sector economic analysis of brucellosis control, a livestock–human transmission model for brucellosis was developed, assuming that most of the transmission of brucellosis originated from cattle, sheep and goats (Fig. 12.2) (Roth *et al*., 2003). To simplify the model, sheep and goats were pooled into one group and the age and sex structure of livestock and human populations was not considered. Parameter estimates were based on official data from the Mongolian Statistical Office, the Ministry of Health and the Ministry of Agriculture. The model took Mongolian health policy into account, adapting assessments to local health policy decision pathways (Habicht *et al*., 1999).

A more detailed approach, using age- and sex-structured disease data and livestock demographic models (Shabb *et al*., 2013) would make such models more realistic but would also require age- and sex-specific seroprevalence data. With the current model, effects of brucellosis on livestock productivity were simulated separately; age- and sex-structured models would allow estimating them directly. Data on effects of zoonoses on livestock production are very scarce and would be urgently required for economic assessments. For the transmission of brucellosis, only serological data was available from livestock. Hence we had to consider a proportion of infectious animals among the seropositive (Zinsstag *et al*., 2005). The transmission to humans of cattle and small ruminant brucellosis was fitted simultaneously, and showed that the transmission from small ruminants dominated. This has recently been confirmed by bacteriological analyses in human brucellosis cases, finding dominantly *Brucella melitensis* and only a few *Brucella abortus* cases (Z. Baljinnyam, 2014, Switzerland, personal communication). Average effective reproductive numbers R_e for the year 1999 were 1.2 for sheep and 1.7 for cattle, indicating relatively low threshold vaccination coverage needed for the interruption of transmission. The

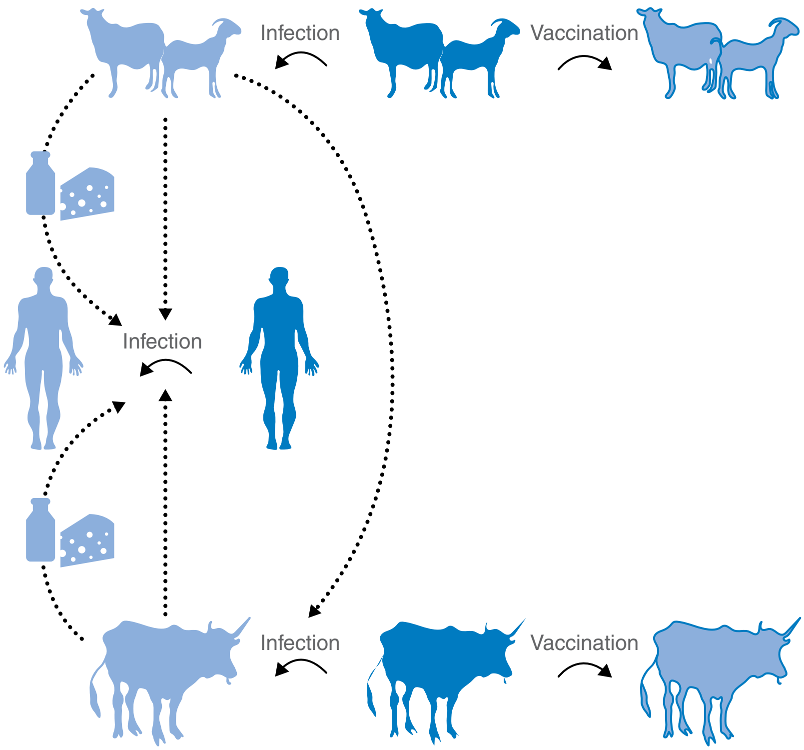

Fig. 12.2. Flow chart of brucellosis transmission. In this, and the following figures, the dark-blue-coloured humans or animals mean infective or infected individuals, light blue means susceptible individuals, border lines symbolize vaccinated individuals, and humans and animals in an upside-down position mean dead individuals. From Zinsstag *et al*. 2005.

livestock–human brucellosis model hence not only elucidated disease ecological aspects but served as the backbone for the cross-sector economic analysis (Häsler *et al.*, Chapter 10, this volume). While livestock brucellosis mass vaccination is not cost-beneficial for public health alone, it becomes highly profitable at a benefit–cost ratio of 3.1 from a societal perspective.

Rabies

Motivated by the Chadian veterinary authorities, a project on dog rabies surveillance and control began in the year 2000. Dog rabies and human exposure data collection was initiated (Kayali *et al.*, 2003a) and complemented by dog demographic studies (Mindekem *et al.*, 2005). Small-scale dog mass-vaccination trials showed that a vaccination coverage of 70% could be achieved and that community participation was high (Kayali *et al.*, 2003b), provided the vaccination was free to the owner (Dürr *et al.*, 2008). However, neither the Ministry of Health nor the Ministry of Agriculture wanted to engage in dog mass vaccination. The Ministry of Health maintained a policy of exclusive provision of post-exposure prophylaxis to exposed humans, which is not always available. This motivated the question of whether, in an African city, dog rabies mass vaccination or human post-exposure prophylaxis was more costly to prevent human rabies. Based on the dog demographic data and 6 years of dog–human rabies surveillance data, a dog–human rabies transmission model was developed for the city of Ndjamena, Chad, as illustrated in Fig. 12.3 (Zinsstag *et al.*, 2009). The effective reproductive number R_e was 1.01, indicating a high potential for fast elimination. A cross-sector economic analysis (Häsler *et al.*, Chapter 10, this volume) showed that dog rabies mass vaccination becomes more profitable after 6 years when compared to human post-exposure prophylaxis only.

In 2012 and in 2013, two vaccination campaigns were conducted targeting dogs in N'Djamena, both achieving a coverage level greater than 70% (Lechenne *et al.*, 2016). These campaigns interrupted transmission as predicted by an accompanying population-based mathematical model (Zinsstag *et al.*, 2017) and largely confirmed the predictions from the earlier model simulating dog mass vaccination (Zinsstag *et al.* 2009) (Fig. 12.3). Analysis of this relatively simple model, which assumed a homogeneous population of dogs fit to the time series data of rabies incidence in dogs, suggested that the basic reproductive number (R_0) would drop well below 1 at this level of vaccination coverage. However, there was a resurgence in cases much earlier than predicted by this model, with the first case occurring 9 months after the second campaign.

To better understand the reasons for this early resurgence, extensions of this model were developed

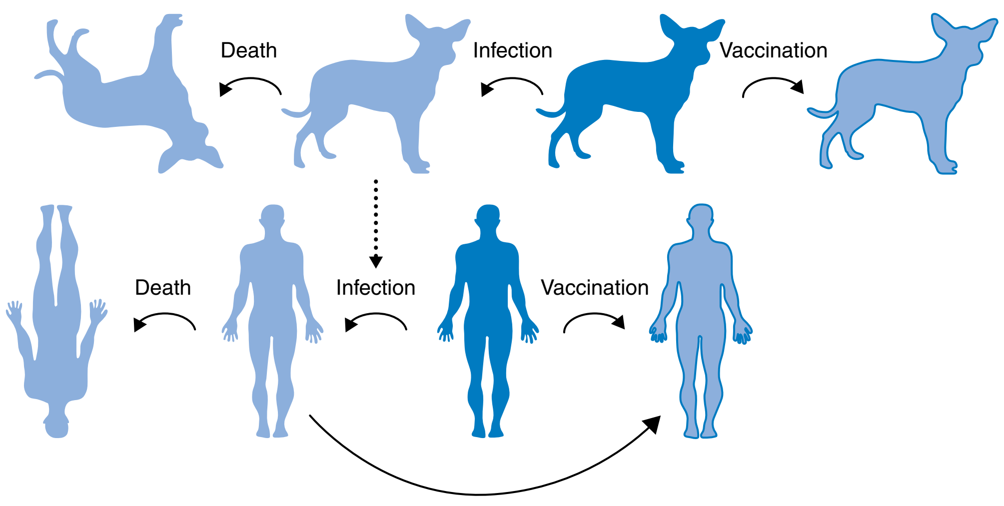

Fig. 12.3. Flow chart of dog–human rabies transmission.

that included: (i) district-level heterogeneity (through a metapopulation model) with movement of dogs between districts; (ii) importation from outside the city; and (iii) under-reporting of dog incidence (Laager *et al.*, 2019). Mathematical analysis and numerical simulations of deterministic and stochastic implementations of these models, fit to district-level incidence data, suggested that importation was the most likely reason for the early resurgence since models including importation provided a much better qualitative and quantitative fit to the data (Laager *et al.*, 2019). This suggested that to sustainably maintain prevention of transmission, vaccination campaigns in the city would need to be complemented by either additional vaccination in the surrounding rural areas and/or other sources of importation, or that the movement of dogs into the city would need to be controlled.

Simultaneously, field studies with the Global Positioning System (GPS) trackers and contact sensors attached to hundreds of dogs provided information on movement and contact patterns (Laager *et al.*, 2018). This data was used to create and validate plausible networks of dog contacts. Simulations of an individual-based rabies transmission on these networks suggested that individual-level heterogeneity can play an important role in rabies transmission and improved targeting of dogs can improve the impact of vaccination strategies. Overall, the analysis suggested that vaccinating 70% of all dogs was sufficient to prevent major outbreaks but insufficient to prevent minor outbreaks and consequently the rabies incidence data in N'Djamena could be explained by a series of importation events followed by minor outbreaks.

Vector-borne Transmission

Mathematical modelling of vector-borne diseases began with Ronald Ross' work in developing and analysing a model to determine a threshold condition for the density of mosquitoes required to transmit malaria (Ross, 1908, 1911; Macdonald, 1956; Smith *et al.*, 2012); George Macdonald fitted this to entomological and epidemiological data. David Rogers extended this Ross–Macdonald model to include both human and animal (cattle) hosts for analysing the dynamics of African trypanosomiases (Rogers, 1988; Welburn and Coleman, Chapter 21, this volume). Since then, models of vector-borne zoonoses have focused on either African trypanosomiases or arboviruses such as West Nile virus and Rift Valley fever virus (RVFV), with some more recent models of *Plasmodium knowlesi* malaria in South-east Asia.

Most of these models have been deterministic compartmental models primarily used to investigate the relative effectiveness of control strategies in reducing transmission. However, they have also been analysed to answer such questions as: (i) Are animals responsible for the sustained transmission of human African trypanosomiasis?; (ii) What is the role of vertical transmission in mosquitoes in the persistence of RVFV?; and (iii) How does West Nile virus persist through the winter in North America? Some detailed individual-based models have also been developed for Rift Valley fever (RVF) and human African trypanosomiasis (Muller *et al.*, 2004). As a further example, we describe a conceptual framework for an RFV model of mosquito–livestock–human transmission (Box 12.1).

Rift Valley fever (RVF)

RVF is a viral zoonosis of increasing global importance (Clements *et al.*, 2007). This acute mosquito-borne disease is caused by a phlebovirus in the family *Bunyaviridae* (Xu *et al.*, 2007) that mainly affects livestock, but can also infect humans and wildlife (Evans *et al.*, 2008). Primary transmission of RVFV to animals results from bites of infected mosquitoes, while most humans become infected by direct exposure to the blood, body fluids or tissue of infected animals (Nguku *et al.*, 2010). RVF infection leads to high mortality and abortion in livestock, and significant morbidity and mortality in humans (Anyangu *et al.*, 2010). Figure 12.4 depicts the transmission cycle. To trigger an RVF epidemic, it is assumed that three main factors need to appear together: (i) infected vectors; (ii) flooding of mosquito breeding sites; and (iii) susceptible host populations (Bird *et al.*, 2009). In the past few years much research focused on vector and climate conditions. Results showed an association between the weather phenomenon El Niño, resulting in prolonged rains together with extended flooding in East Africa, and the subsequent occurrence of large RVF-infected mosquito populations (Anyamba *et al.*, 2010). Although many outbreaks from the past could be linked with such events, remote sensing appears to be insufficient to predict RVF outbreaks accurately and strategies to control the disease in livestock and humans are poorly understood and

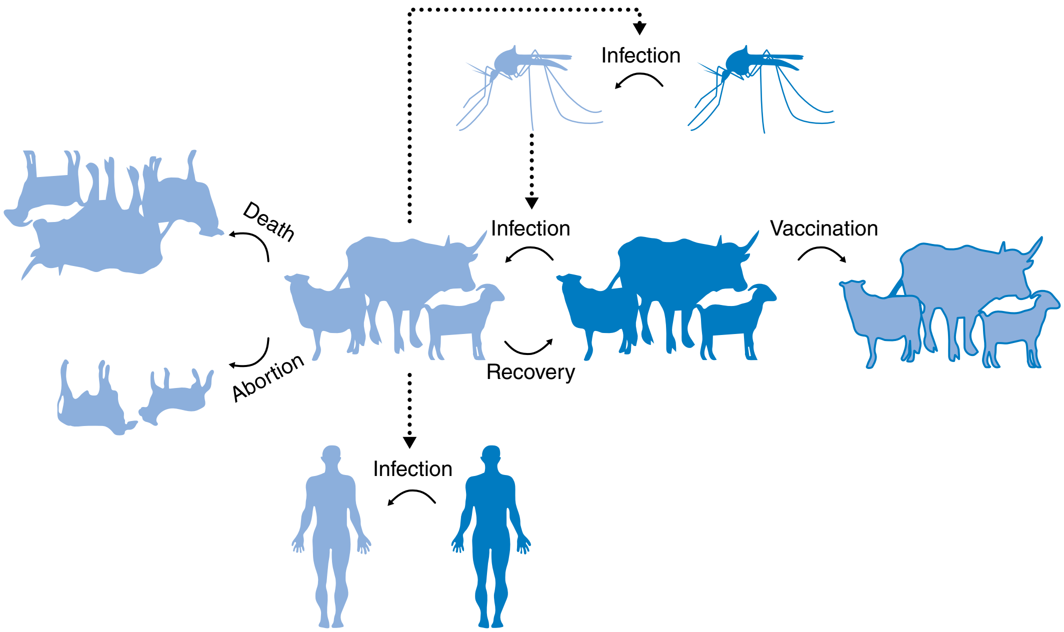

Fig. 12.4. Flow chart of the individual-based Rift Valley fever (RVF) transmission model.

not yet sufficient to significantly reduce the impact of an epidemic (Geering *et al*., 2002; Schelling and Kimani, 2007).

An individual based model (IBM) for pastoral livestock populations was developed to assess the impact of interventions and identify the most cost-effective interventions for RVF in Kenya. The model reflects, in a simplified way, the demographic dynamics of the most economically important animals (cattle, sheep, goats and camels) in normal and drought periods, with and without epidemics of RVF, as well as simulating livestock parameters with and without RFV control measures. The IBM tracked the individual state of each animal (species, sex, age) over time, allowing transitions between susceptible, exposed, infectious and recovered (SEIR) diseased states during an RVF epidemic. It also included RVF-induced mortality and abortion and the sale and slaughtering of animals that pose risks for human infection. This allowed the simulation of RVF control strategies and the subsequent impact of livestock infection on human risk and livestock mortality. Furthermore, the model followed the immunization levels of animals after an RVF infection or a vaccination, to identify the time period when the animal host population is protected from subsequent RVF epidemics (Box 12.1; Fuhrimann, 2011).

Box 12.1. Individual-based RVF transmission model.

The model assigns each host to the state variables, species, gender and age, to incorporate the livestock herd structure and simulates dynamic processes on an individual level. Hosts can be removed from the model, depending on the turnover probabilities of mortality, selling and slaughtering. When a female host reaches the adult age, it is assigned to the state variable fertile and will then have a probability of becoming pregnant and going through a gestation period. If the pregnancy is not ended by abortion, it will give birth to an offspring. After such birth or abortion, the female enters a waiting stage in which it cannot get pregnant for a certain period. RVF is simulated as a susceptible-exposed-infectious-recovered (SEIR) model. During a specified time period, a susceptible host can become infected with RVF with a constant infection probability. After being infected it enters the incubation period (exposed state) before becoming infectious – also to people – and for the time of acute infection. During the latter stage, the host has an increased probability of death and abortion. Survivors recover with a lifelong immunity to the disease. The transmission to humans is assumed to be proportional to infectiousness in animals (Fuhrimann, 2011).

The IBM approach improved our understanding of pastoralists' livestock management during normal and drought periods. Based on the outcomes of the different model scenarios, recommendations on control options can be formulated from the societal perspective for more appropriate allocation of limited resources and to facilitate intersectoral RVF planning by governmental and non-governmental agencies. The model provided the proportion of affected animals, grouped by species, age classes and sex. Therefore, baseline and RVF-attributable mortalities can be compared, to determine the impact of RVF on mortality. The results suggest that infected sheep and goats are most likely to spread the disease through livestock trade, and slaughtered infected sheep are an important risk factor to human RVF infection. Such results assist the development of future studies to assess the effect of control measures against RVF before an outbreak occurs. The ratio of susceptible to immune hosts can also support the existing prediction system by further consideration of the susceptibility of a host population. The model can be extended to include transmission to humans, which provides the interface to public health. Such a model would allow assessing the effects of interventions in animals on human health, similar to the brucellosis and rabies models above. To validate such an extended livestock–human RVF model, a time series of RVF incidence in livestock and humans would be needed. A validated model could then provide insight into future joint livestock and public health contingency plans (Fuhrimann, 2011; Kimani *et al*., 2016). Due to lack of available data, the model does not explicitly model cross-species transmission to humans, which would be a valuable extension. This example sheds light on various ways that models can be parameterized. As applied here, a 'bottom-up' approach estimates parameter values (ideally with distributions) from the literature. Alternatively, models can be fitted to observations (of prevalence or incidence) as in the above examples on brucellosis and rabies. The latter is much less common but potentially more robust, and provides greater confidence in predicting outside the observed situations.

Environmental and Foodborne Transmission

Animal-borne infectious diseases can be transmitted to humans by the environment. Cattle may die from anthrax and be consumed by humans. Rodents excrete *Leptospira* spp. in their urine and contaminate stagnant water from which humans become infected. Food contaminated with *Salmonella*, *Campylobacter* or *Escherichia coli* originating from animals is the source of a huge burden of foodborne illnesses. Foodborne trematodes, and particularly

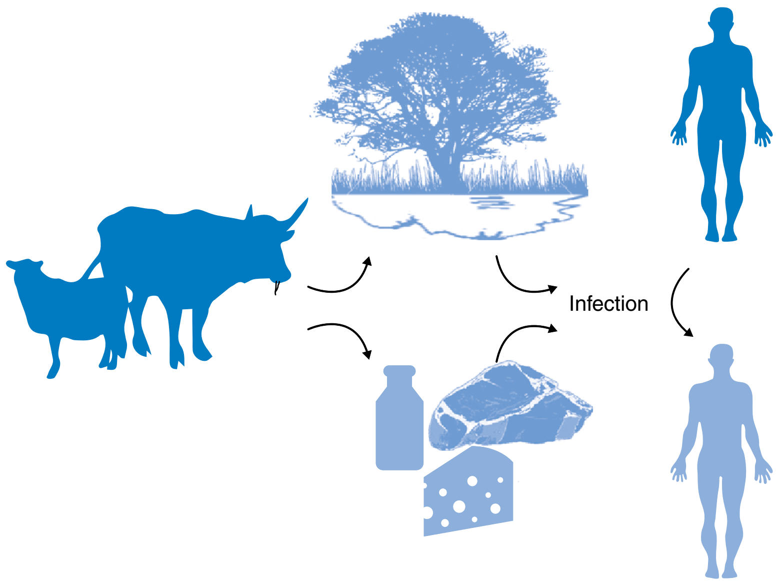

Fig. 12.5. Simplified schematic of environmental and foodborne transmission of zoonoses.

the fish-borne liver flukes, have a complex life cycle including humans, reservoir mammalian hosts, snails and secondary intermediate aquatic hosts. Figure 12.5 shows a simplified schematic of how animals may contaminate the environment (soil, water) and food, which are then sources of infection for humans.

More detailed ecological studies are needed to estimate the contamination of the environment and food. Moreover, pathogens may decay in the environment or grow in food. As an example we can consider the contamination of milk with enterobacteria. Bonfoh *et al.* (2006) followed the contamination level of milk in the peri-urban dairy production system of Bamako from the milking, through transport to the market (Bonfoh *et al.*, 2006). This type of statistical modelling of contamination is called quantitative microbial risk assessment (QMRA), which has recently been combined with material flow analysis (MFA) for wastewater-related disease risks (Nguyen-Viet *et al.*, 2008; Nguyen-Viet *et al.*, Chapter 13, this volume).

Adding the human interface to animal-source foodborne illnesses requires a detailed understanding of food processing and consumption patterns and frequencies. A case-control study attempted to establish a direct link between human health and milk consumption in Mali, but failed to do so (Hetzel *et al.*, 2004). More sophisticated models have been developed for *Campylobacter* transmission, where detailed data are available. For example, Nauta *et al.* (2007) modelled the dynamics of the pathogen population from 'farm to fork'. The *Campylobacter* model incorporates all steps through the chicken meat production chain to the food storage and processing at home, including potential cross-contamination of salad. Integrated surveillance for food safety is further detailed by Aenishaenslin *et al.* (Chapter 9, this volume).

More challenging are transmission models where the main route of infection is via the environment. Pathogen survival in the environment is determined by numerous factors simultaneously. A good example to demonstrate the complex interactions is leptospirosis. Virtually all mammalian species can carry leptospires and many act as a source of infection to humans or other animals. Livestock and rodents are of primary public health interest. There are about 250 pathogenic serovars, which have varying degrees of host specificity and differ in terms of pathogenicity and virulence. Leptospirosis in humans presents with a wide variety of clinical manifestations and mostly non-specific symptoms which resemble those of other febrile diseases. Hence it is frequently misdiagnosed as dengue fever, RVF, brucellosis or influenza, and under-reporting appears to be common in many countries. Transmission to humans can either be by direct contact with the urine of infected animals or by contact with a urine-contaminated environment. The disease exhibits a strong seasonal pattern, which is linked to rainfall, animal, agricultural or occupational cycles. However, the relationship between climatic, soil and anthropogenic variables is complex and poorly understood. Outbreaks of leptospirosis are common, and in countries with a high burden it is particularly difficult to differentiate between the seasonal endemic situation and local outbreaks if only aggregated data are available. Outbreaks are often reported after heavy rainfall, floods and other natural disasters. The reasons range from more frequent human water contacts to less predatory pressure on rodent populations. Finally, there are two distinct epidemiological patterns of leptospirosis. In rural areas, the disease is strongly linked to agricultural activities; in urban slums, sanitation infrastructure and sewage facilities are important determinants. How this system can be simplified depends on the setting, but even more on the question that should be addressed. It is relatively easy to capture the dynamics of seasonal variation with time series analysis (ARIMAX) models. However, these are not able to simulate the impact of potential interventions and are limited in the ability to forecast the future. Several deterministic models have been developed, but due to the lack of detailed knowledge and data, a thorough model validation was not possible. Since an important objective is the prediction of future outbreaks, spatio-temporal Markov models, as recently developed for meningitis in Africa, might be a promising approach (Agier *et al.*, 2013).

Opisthorchiasis is a foodborne disease caused by the trematode parasites, *Opisthorchis felineus* and *O. viverrini*. As illustrated in Fig. 12.1, the parasites have a complex life cycle, where adult worms live in the bile ducts of humans and other mammalian hosts, such as cats, dogs and foxes. Eggs pass out through faeces and, if they enter water bodies, can infect faucet snails. Infected snails release larvae that penetrate and infect fish. If these fish are eaten by humans or other animals without sufficient cooking or freezing, they in turn reinfect the mammalian hosts. Infection can last years and chronic heavy reinfection can lead to severe liver pathologies, including the bile duct cancer, cholangiocarcinoma. *O. viverrini* is common in South-east Asia, while *O. felineus* is prevalent in Eastern Europe and Russia. It is assumed that *O. viverrini* is primarily anthroponotic while *O. felineus* is zoonotic but this has not been conclusively shown. A deterministic compartmental model of *O. viverrini* transmission was developed and calibrated to data from southern Lao People's Democratic Republic (Lao PDR), including prevalence in humans, cats, dogs, fish and snails (Bürli *et al*., 2018). The analysis included the derivation of type reproductive numbers (which are equivalent to calculating the basic reproductive number while excluding certain host types) for humans, dogs and cats, and their expected distribution. The analysis suggested that is likely that humans are both sufficient for transmission (i.e. transmission can persist if only humans are in the population) and necessary for transmission (i.e. transmission cannot persist if humans are removed from the population); that it is possible but unlikely that dogs and cats are sufficient for transmission to persist; and very unlikely that dogs and cats are necessary for transmission to persist. Such analysis has not been carried out for *O. felineus*. We expect that humans are neither sufficient not necessary for transmission but maintenance hosts have not yet been identified.

Conclusion

Animal–human transmission models require an ecological perspective, an understanding of the biology of the animal–human interface as well as animal and human demographic processes and their interaction. These models need to be properly calibrated and validated with ecological and epidemiological data to fulfil their potential. Here we presented some examples of directly transmitted, vector-borne and environment and foodborne zoonoses, which provided the basis for cross-sector economic assessments of interventions in animals and humans. A further example of cattle–human transmission of *Mycobacterium bovis* is presented by Tschopp and Yahyaoui in Chapter 22, this volume. Future research should: (i) address the heterogeneity and network nature of the animal–human interface, moving towards a more realistic representation of zoonoses transmission; (ii) include the ecological boundaries, such as competition over resources, which further determine animal demographic processes and indirectly the transmission of zoonoses; and (iii) complement animal–human models with a cross-sector economic framework to identify the most cost-effective interventions (Narrod *et al*., 2012; Häsler *et al*., Chapter 10, this volume).

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13 A One Health Perspective for Integrated Human and Animal Sanitation, Nutrient Recycling and Climate Change

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Introduction

Improving health and conserving natural resources for sustainable development are part of the Sustainable Development Goals (SDGs), namely 3 (good health and well-being), 6 (clean water and sanitation), 14 and 15 (life below water and life on land). Both water and environmental sanitation are important factors influencing human health status. It has been estimated that 2.2 billion people around the world lack safe drinking water and over half of the global population, or 4.2 billion people, lack safe sanitation (UNICEF and WHO, 2019). With the extensive use and depletion of natural resources, the question of how to effectively use natural and environmental resources such as those present in excreta is of highest priority (Waltner-Toews, 2013). Studies have highlighted a number of issues regarding recovery and reuse of resources from waste and their impact on health (Nhapi *et al*., 2003; Miller, 2006).

It is also evident that social, economic and cultural factors play a crucial role in achieving health improvements (Marmot, 1998; Anderson *et al*., 2003). Numerous studies have examined the impact of physical, socio-economic and cultural environments on health and on how to reduce health risks by improving these environments. However, the assessments of the impact as well as the approaches to improving health and environment have often been conducted in relative isolation, with the danger that health programmes might put environmental sustainability at risk, and vice versa. For example, Morris *et al*. (2006) found that the combination of health and physical environments without sufficient consideration of social, economic and cultural factors led to a narrow perspective usually centring on specific environmental hazards. They argued that it is necessary to have a health-determining role for the environment acting through broader psychosocial mechanisms. In other studies, the links between health and society were addressed without adequately taking the physical environment into account (Yen and Syme, 1999; Marmot, 2005).

A review of the literature shows a dearth of assessments offering approaches that effectively integrate health and environmental factors. This is particularly relevant in discussions on the development of

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urban and peri-urban areas, where vulnerable populations bear the brunt of the resulting health risks from poor environmental sanitation and uncontrolled urbanization (McMichael, 2000; Moore *et al*., 2003; Montgomery and Elimelech, 2007).

In developing countries, the management of human excreta is significantly hampered by a lack of appropriate sanitation technologies, posing a significant challenge to human and environmental health. This is compounded by a similar challenge posed by animal waste. In Vietnam, large volumes of waste from livestock such as poultry, ruminants and especially pigs, raised to meet the country's high pork consumption, are reused as fertilizers and feed in agriculture and aquaculture. Both human and livestock waste contribute to family livelihoods, replacing the need for expensive and potentially hazardous chemical fertilizers. Unfortunately, human and animal waste is usually not managed properly, which consequently becomes a source of pathogens affecting health and the environment.

Climate change can exacerbate the health risks from deficient sanitation systems (Cissé, 2013; Sherpa *et al*., 2014). Under climate change, human and animal waste left untreated in the environment in many countries, particularly in low- and middle-income countries (LMICs) can be washed away by heavy rainfall runoff and flooding events. This can harm the quality of water resources (both surface waters and groundwater) and contribute to the increase of waterborne and foodborne disease burden (Cissé *et al*., 2018; Zinsstag *et al*., 2018; Cissé, 2019). These climate-related risks are among the major emerging and growing public health issues (e.g. current and projected climate change impacts) for which there are both knowledge gaps and challenges with undertaking health and environmental risk assessments.

As an approach being increasingly used for health and environmental assessments, quantitative microbial risk assessment (QMRA) estimates the infection risk from an exposure and can also estimate disease risk, which allows for assessment of critical control points (CCPs) in food chains (production, transformation and consumption) and sanitation systems (Haas *et al*., 1999). Over the last decade, QMRA has been used to assess the health risks in drinking water (Howard *et al*., 2006; van Lieverloo *et al*., 2007) and in wastewater management (Westrell *et al*., 2004; Eisenberg *et al*., 2008). From an environmental health perspective, QMRA has been used to assess the infection risk and, subsequently, high disease risk for the population in contact with wastewater (An *et al*., 2007; Mara *et al*., 2007; Diallo *et al*., 2008; Seidu *et al*., 2008).

Another useful tool for environmental assessment is material flow analysis (MFA), which examines the flows of resources and how they change as they pass through a system. It has been applied as a tool to identify environmental and resource management problems and develop appropriate measures (Baccini and Brunner, 1991; Brunner and Rechberger, 2004). An interesting application has been in optimizing water and nutrient management in environmental sanitation systems in Vietnam and China (Huang *et al*., 2007; Montangero *et al*., 2007). Despite its potential to provide useful information for the safe use of natural resources and reuse of waste products, it does not provide information on potential health risks and CCPs.

For both MFA and QMRA, both quantitative and qualitative knowledge are required to comprehensively assess public health risks, specifically information on the human behavioural dimensions. Quantitative epidemiological studies can identify possible health risks within food chains and environmental sanitation systems (Beaglehole *et al*., 2005). Cultural epidemiological studies on how health and risk are perceived by different populations through experiences, meaning and behaviour related to a particular risk also offer important insights (Weiss, 2001; Whittaker, 2015; Whittaker *et al*., Chapter 7, this volume). However, even such comprehensive approaches do not address the issues of resource flows or cycles. In addition, social anthropological approaches focus on people and their responses to health risk as processes leading to negative outcomes (vulnerability) or positive outcomes (resilience), without consideration of the larger social-ecological systemic context (Obrist, 2006). Thus, an important consideration to address these includes access to livelihood assets and to health, environmental and social services (Obrist *et al*., 2007).

Given these challenges, an integrated approach to human and animal waste assessment and management may be more effective for tackling complex problems than employing a single or multidisciplinary approach. A One Health approach emerges as a good candidate for this as it addresses the complex interactions of human, animals and environment. One Health can be defined as the added value in terms of animal and human lives saved, financial savings and improved ecosystem services from a closer cooperation of human and animal health as compared to single-sector approaches (Zinsstag *et al*., 2012, 2015; Häsler *et al*., Chapter 10, this volume; Zinsstag *et al*., Chapter 31, this volume).

In this chapter, we present our experience of developing a conceptual framework for integrated health and environmental assessment, combining health status, physical, socio-economic and cultural environments to improve health and minimize environmental impact. We will focus on how the framework was used to manage human and animal excreta in Vietnam and the added value offered from an integrated assessment.

Conceptual Framework Development

Description

The details of the conceptual framework have been published previously (Nguyen-Viet *et al*., 2009). The framework (Fig. 13.1) starts with an analysis of health status, as well as the status of the physical, social, cultural and economic environments. Starting with an analysis of the routine databases, health status can be further assessed through specifically designed epidemiological surveys. Similarly, the status of environmental sanitation – that comprises excreta, wastewater and solid waste management, and drainage and water supply management – can be evaluated through surveys, observation and mapping of water supply, excreta, wastewater, solid waste management and drainage infrastructures and services, while taking into account the technical, economic, institutional and organizational factors. Furthermore, interactions between waste management and the food chain (Gordon *et al*., Chapter 25, this volume), crops and livestock can also be

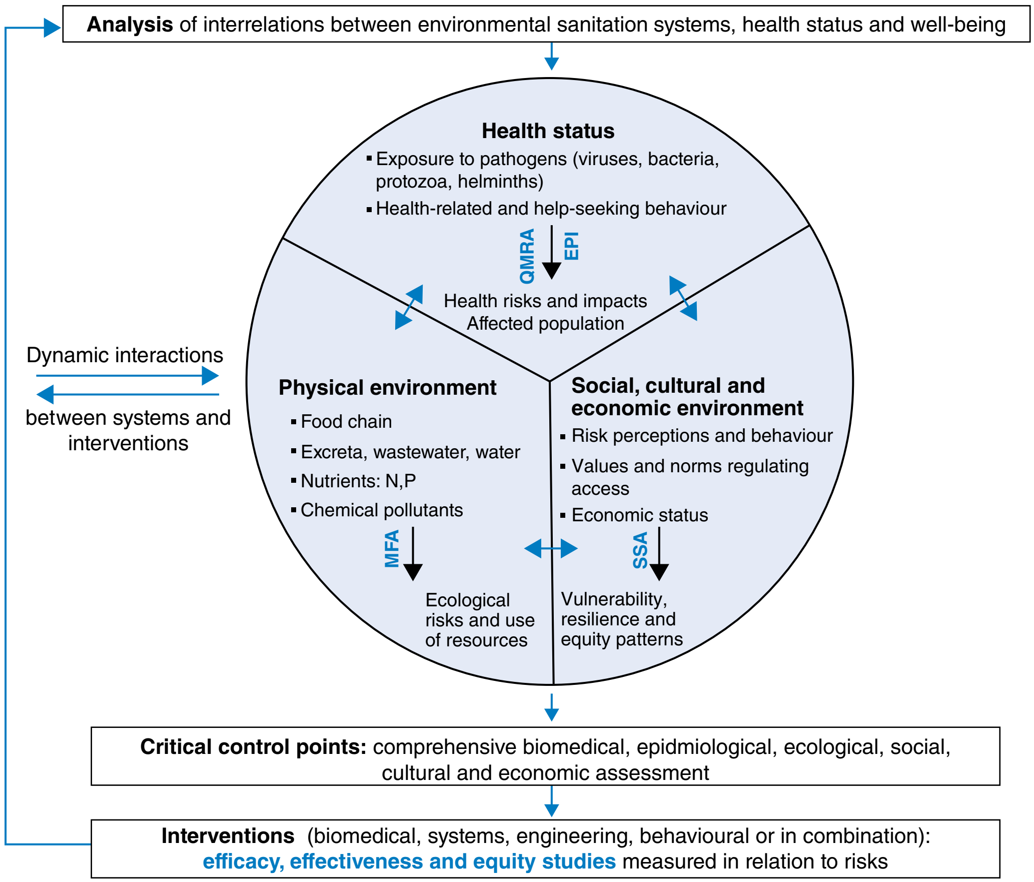

Fig. 13.1. Conceptual framework of integrated assessment for health, environmental sanitation and society. EPI, epidemiology; MFA, material flow analysis; QMRA, quantitative microbial risk assessment; SSA, social science analyses. From Nguyen-Viet *et al*., 2009, reproduced with permission.

included (Bonfoh *et al*., 2006). Combined, this information allows description of the current status of environmental sanitation systems, health and well-being of the local population and the key interrelations. They provide the basis for understanding the key issues for the improvement of health and environment in a given area or setting. Furthermore, today, these multiple dimensions need to be analysed also considering three very important frameworks for global change and global health: (i) the SDGs; (ii) the Sendai Framework for Disaster Risk Reduction; and (iii) the Paris Agreement on Climate Change (Vidal, 2015; Aitsi-Selmi and Murray, 2016; George *et al*., 2019; Thapa *et al*., 2019).

Physical environment

The physical environment describes the status of the environmental sanitation system. The MFA is straightforward to apply and proven to be effective in developing country contexts with limited data availability (Montangero, 2007; Montangero *et al*., 2007). The main steps of MFA are the conceptual representations of processes, their interaction with flows of goods (system analysis), and the quantification of mass flow of goods and substances. This tool provides useful information for identification of key factors determining material flows (CCPs) and the planning of interventions aimed at reducing resource consumption and pollutant loads into the environment. In our context of environmental sanitation in LMICs, the focus rests on the 'goods' (e.g. faeces and human and animal waste) that play an important role with regard to human health and ecological impact and the 'substances' these goods contain.

Social, economic and cultural environment

This component entails the approaches of medical anthropology, cultural epidemiology and social economics, grouped broadly as social science analyses (SSA). A main focus of the approach lies in considering the vulnerability and resilience of the populations (Obrist, 2006) and their risk perceptions gained through experiences, meaning and behaviour related to particular illness entities (Kleinman, 1981; Weiss, 2001; Whittaker *et al*., Chapter 7, this volume). Furthermore, economic appraisal is used to assess the costs and cost-effectiveness of proposed interventions. Combining economic appraisal with epidemiological, social and cultural data allows for analysis on how a more equitable access to resources and services can be achieved and to what degree (Gold *et al*., 1996; Hutton, 2000; Häsler *et al*., Chapter 10, this volume).

Health status

In this framework, classical epidemiology (Beaglehole *et al*., 2005), cultural epidemiology (Weiss, 2001) and QMRA are proposed as key methodologies to assess health and identify the determinants of disease burdens. While the basic approaches of epidemiology are well known, validated and applied (Beaglehole *et al*., 2005), QMRA has been more recently applied in health status assessments and is recommended in risk assessments for the safe use of wastewater, excreta and grey water and for drinking water quality (WHO, 2006b,c). The addition of QMRA to epidemiology is motivated by the quantitative aspect of this method, which calculates the estimated risk of having infection and disease burden related to pathogen exposure by combining available information on exposure and dose–response (Haas *et al*., 1999; Vose, 2000; Pintar *et al*., 2012). QMRA has been used in various risk assessments and shown to be effectively applied in developing countries, even with limited data (Howard *et al*., 2006; Benke and Hamilton, 2008). The identification of pathogens (viruses, bacteria, protozoa and helminths) will effectively complement the epidemiological methods (Fig. 13.1).

Comprehensive critical control points (CCPs)

CCPs are conventionally defined in food safety as any step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level (National Advisory Committee on Microbiological Criteria for Foods, 1997). CCPs in our framework resulted from the analyses of the three components described above. Therefore, integrated CCPs are taken into account and identified from different perspectives such as: (i) comprehensive biomedical, epidemiological assessment (health); (ii) social, cultural and economic assessment (social sciences); and (iii) environmental assessment (physical environment) (Fig. 13.1). Our CCPs retain the traditional definition related to food chains, but are further complemented by other risks relating to pathogens in drinking water, wastewater, excreta and solid waste. They also include the social and cultural perspectives that consider the concept of vulnerability and resilience.

Interventions

Once CCPs are identified, interventions can be comparatively assessed for optimal contribution to improving health and minimizing impact on the environment and the use of resources in a given area. Interventions established based on these components will be integrated as they will take into account the needs and the demand of the populations concerned. Consequently, this will allow priority setting based on reconciled needs and demands. Figure 13.1 further shows the dynamics between the components of the framework and the interventions. The iterative process ensures that interventions are tailored to the needs and demands of any given setting and allows respective readjustments and strengthening of any intervention or component of an intervention.

Case Study: Integrated Assessment of Human and Animal Waste Management in Vietnam

Background

We applied this framework as a case study in Hanam Province, Vietnam. This section discusses how the framework is useful to comprehensively assess the impact of combined human and animal sanitation and address the One Health application for the sanitation issue. Hanam was selected as a peri-urban study site because it offered a good setting for studying a system combining human and animal sanitation. In this area, human excreta and animal manure are used together with wastewater in agriculture and aquaculture (Fig. 13.2). Most households (85%) are engaged in agricultural activities; they are predominantly smallholders and often raise between two and 20 pigs on land that is simultaneously residential, agricultural, aquacultural and horticultural. This use of waste raised issues for environmental sanitation, agriculture and health and well-being. Three components of the framework were implemented, namely environmental, health and socio-economic assessment leading to the identification of CCPs.

Physical environment

We used MFA for analysing environmental sanitation and agricultural systems with the emphasis on nutrient flows of nitrogen (N) and phosphorus (P). The results, illustrated in Fig. 13.3, revealed that the agricultural system was a significant source of nutrients (N and P), which affect the surrounding environment, mainly due to the overuse of chemical fertilizers (CCPs) (Nga *et al*., 2011). Annually, in the study area, there were 103 ± 39 t (mean ± standard error) of N released into the atmosphere, 25 ± 3 t of N leached to the surface water, and 14 ± 2 t of P accumulated in the soil, all originating from the applied chemical fertilizers. In addition, the sanitation system was also a critical source of nutrients that entered the surface water. A volume of 69

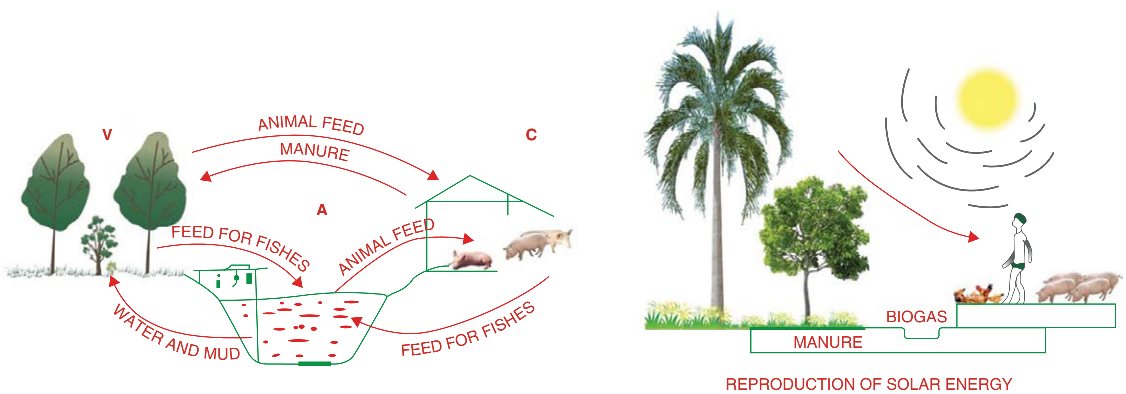

Fig. 13.2. Integrated crop (V) – fishery (A) – livestock (C) (V-A-C) in Vietnam. Adapted from Center for Public Health and Ecosystem Research, Hanoi University of Public Health, 2020.

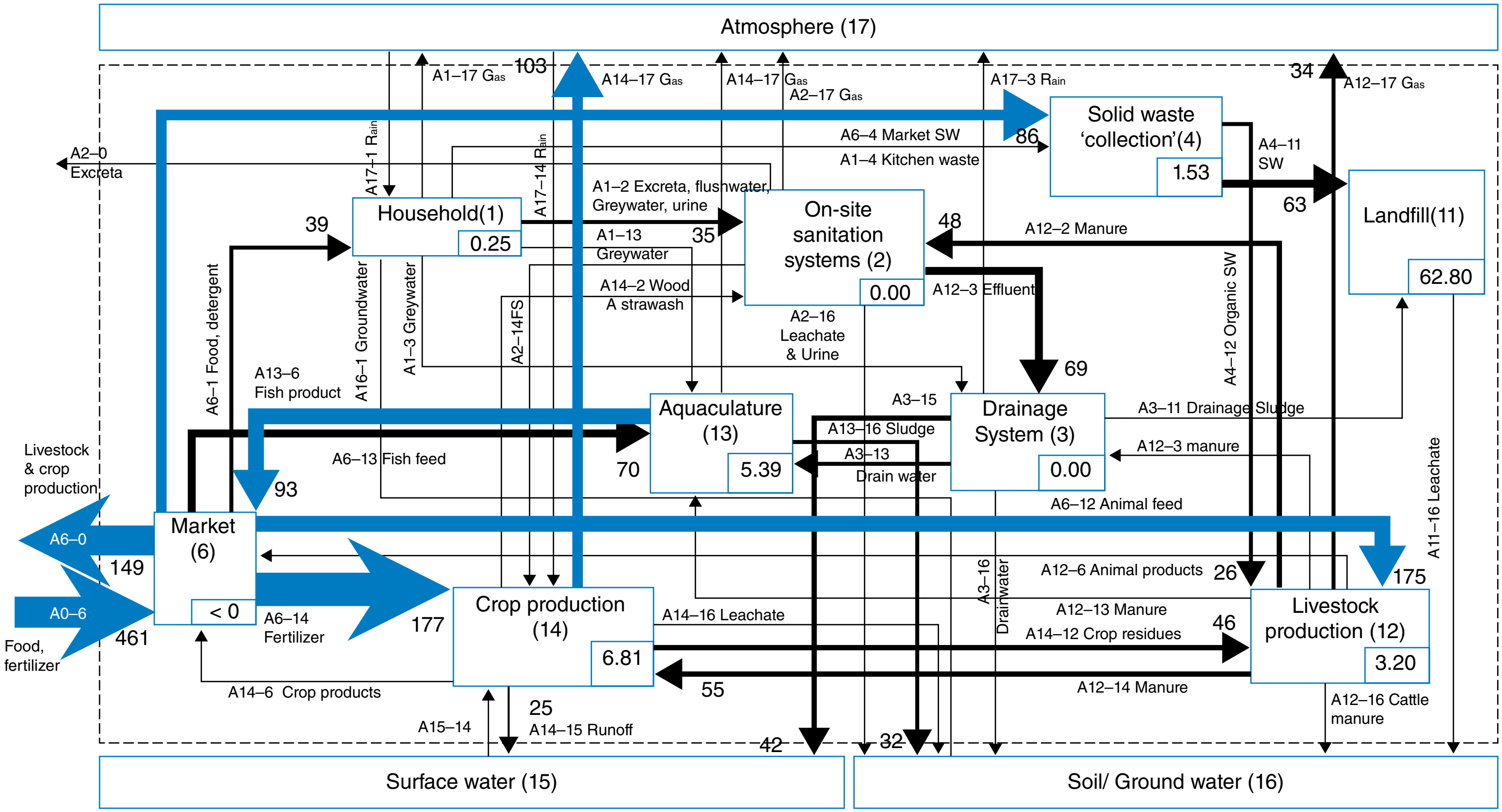

Fig. 13.3. Material flow analysis (MFA) results for nitrogen (t/year). Boxes and arrows represent processes and nutrient flows, respectively. The wider arrows represent the bigger nutrient flows among processes. The narrow arrows indicate comparatively very small nutrient flows. The number in each process box represents the amount of nutrients stocked in that process.

± 6 t of N and 23 ± 4 t of P came from households through effluents of on-site sanitation systems (such as latrines and septic tanks) and were directly discharged to surface water every year. Moreover, the whole system annually generated a large nutrient source (214 ± 56 t of N; 58 ± 16 t of P) in the form of wastewater, faecal sludge, animal manure and organic solid waste. The validated MFA was used to model different scenarios for the study site. The first scenario demonstrated that if nutrient management was not improved, wastewater as well as faecal sludge and organic solid waste would be expected to double in the year 2020 as compared to that in 2008. The second and third scenarios revealed possible strategies to significantly reduce environmental pollution and reused nutrient sources predicted to be available in the year 2020 (Nga *et al*., 2011).

Health status

A set of epidemiological and QMRA studies were carried out to look at the health effects of wastewater and excreta reuse. Two cross-sectional surveys were conducted during the rainy and dry season in Hanam to identify prevalence and risk factors for helminth and protozoal infections (Pham-Duc *et al*., 2013). Results showed that 302 people (47.6%) in the rainy season and 336 people (46.3%) in the dry season were infected with at least one of the three helminth species. Furthermore, protozoal intestinal infections were also diagnosed. *Entamoeba histolytica* (6%) and *Giardia lamblia* (2.4%) were recorded in the rainy season and *E. histolytica* (6.7%), *Cryptosporidium parvum* (9.6%) and *Cyclospora cayetenensis* (2%) in the dry season (Pham-Duc *et al*., 2013). A case-control study for *E. histolytica* infection was also conducted to assess the risk factors associated with handling practices of wastewater and excreta use in agriculture and aquaculture in Hanam (Pham-Duc *et al*., 2011). Analyses revealed that the risk factors included: (i) direct contact with a domestic animal; (ii) not using or rarely using soap for hand washing; and (iii) lower socio-economic status. A nested case-control study assessed the incidence of and risk factors for diarrhoeal disease among people living and working in the same areas. The estimated annual risks of diarrhoea were at least threefold greater than the upper threshold risk of 10^{-3} per person/year; and the annual burden of diarrhoeal disease was significantly higher than the health target of 10^{-6} disability adjusted life years (DALYs) (≤ 1 DALY per million persons) recommended by the World Health Organization (WHO). The annual diarrhoeal risk caused by exposure to biogas effluent through irrigation activities ranged from 17.4% to 21.1% (*E. coli* O157:H7), 1.0–2.3% (*G. lamblia*) and 0.2–0.5% (*C. parvum*), while those caused through unblocking drains connected to biogas effluent tanks were 22.0% (*E. coli*), 0.7% (*G. lamblia*) and 0.5% (*C. parvum*) (Le-Thi *et al*., 2016). In addition, another study on human exposure to human faeces during handling excreta in agriculture showed that farmers ingest 91 mg of excreta/year (95% confidence interval: 73–110 mg). This study adds an important contribution to more robust quantitative microbial risk assessment and health impact assessment related to soil-transmitted helminth (STH) infections and diarrhoea in Vietnam and other similar settings where excreta is used as fertilizer (Van Vu *et al*., 2019).

Social, economic and cultural environment

One of our studies investigated the perception of health risk and ability to prevent risk caused by wastewater and excreta reuse. The first survey focusing on threat appraisal found that people recognized the black colour and smell of wastewater, the smell of excreta, inappropriate practices of excreta management and suspected diseases associated with contact with excreta and wastewater as threats (Tu *et al*., 2011). We also implemented a study in Kim Bang District, Hanam Province to assess willingness to pay for construction of flush toilets at the household level. The contingent valuation method (CVM) was used in this study. This is a survey-based economic technique, which directly questions individuals as to how much they are willing to pay for a change in quantity, quality, or both, of a particular commodity. We found that 63% of the studied households were willing to pay for construction of flush toilets. The average willingness-to-pay level was US$800. There was no statistically significant difference in the willingness-to-pay level by socio-economic status.

The application of the framework for the specific case study in Vietnam identified the distinctions between the theoretical organization of the framework and the fluid interactions that occurred in the real-life case study. Ideally, all components of the framework should be prepared such that they begin at the same time. This would allow complementary components to be combined to identify CCPs, particularly for the QMRA and MFA. In practice, diverse information from the three components was combined as follows. The result of MFA identified the CCPs in the environment, providing a basis for health status research. The actual risks identified by the epidemiological studies supported and complemented the QMRA, which assessed the risk of infection, giving CCPs in terms of health risk. The socio-economic and cultural assessment looked at the behaviour and perception of participants with regards to these CCPs and the cost and willingness to pay for sanitation options. Our research revealed that participant perceptions of the health and environmental risks of intensive waste recycling and reuse within their agroecosystem was not consistent with the actual risks measured. However, they were willing to pay for better sanitation facilities. The combined assessment showed the importance of identifying CCPs in this system to be targeted for interventions. On-site sanitation systems and the combined management of human and animal waste (discussed in the next section) appear to be promising interventions. The CCPs also rely on the perceptions of the community that need to be addressed in the intervention so that it can be effectively implemented. Interventions identified by the concerned communities should be used to further validate the proposed integrated framework.

Benefit of One Health for sanitation: combined treatment of human and animal waste

Vietnamese livestock production is increasing rapidly, particularly for ruminants with the development of a dairy industry, reflected in increasing annual per capita milk consumption. In 1990, the ruminant (cattle and goat) population was 3.5 million – by 2017, it had grown to 8.6 million. The pig and chicken populations increased steadily over these two decades, but slowed down with the steep increase of ruminants; in 2018, there were 30 million pigs. Subsequently, large amounts of manure are produced, which may be a hazard to the environment (e.g. pollution of surface and groundwater by excess nutrients and chemicals) and human health. Currently, there is national and international attention on environmental risk management (including cost–benefit assessments, for example, in biogas production from livestock waste) with regard to climate change and environmental hazards. However, there is no combined tool that balances human health and preserving ecosystem services.

In most rural and peri-urban settings of the country, mixed agricultural and residential land use causes humans and animals to live in close proximity, highlighting the importance of managing the health and environmental risks of human and animal waste (Fig. 13.2). Despite the national government's attempt to manage these through the new livestock centralization policy, it is unlikely to be implemented in the near future. As current practice, animal and human waste are separately treated or, in some places, they are mixed for treatment prior to use as fertilizer. While the risks of human waste are largely known, the risks associated with livestock waste are not so well known and tend to be perceived as causing lower risks than human waste. Human health hazards of livestock waste, which are often processed together with crop residues, may include zoonotic pathogens and residues of agrochemicals and drugs. Due to the proximity of animal and human waste disposal, storage and reuse, as well as the close proximity of human and animal living quarters, safe practices in livestock and human waste management are needed for mitigating risks posed to human health and the environment. For such a multifaceted task, participatory action research, involving a wide range of stakeholders, institutions and policy makers can promote better water management practices that integrate management of wastewater, human and animal waste and agricultural runoff.

The intervention aimed to improve the current storage practices of human excreta and identify the best option for the safe use of excreta in agriculture. We studied the influence of different additive materials (lime and rice husk) and aeration conditions on *Ascaris lumbricoides* egg die-off in 24 vaults of an experimental excreta storage unit. Excreta samples were collected once every 2 weeks over 181 days. Temperature, pH and moisture content were recorded. *A. lumbricoides* eggs were quantitatively analysed by the Romanenko method, which identified and counted live and dead eggs. From the first sampling (0 storage days) to the final sampling (181 storage days) the average percentage of viable *A. lumbricoides* eggs decreased gradually from 76.72 ± 11.23% (mean ± standard deviation) to 8.26 ± 5.20%. The storage time and the high pH value significantly increased the die-off of helminth eggs. Over 181 storage days, all vault options effectively reduced *A. lumbricoides* egg die-off. The best vault option, with aeration and 10% lime per total weight, met the WHO standard (1 egg/l) for excreta treatment for safe use of wastewater, excreta and greywater in agriculture and aquaculture on the 111th storage day (WHO, 2006a).

We also introduced an intervention to improve the operation of biogas systems treating livestock waste in Vietnam through the improvement of farmers' knowledge and practices of the safe and appropriate use of household biogas units (HBUs). The results show that there was a significant difference in the knowledge and practices of biogas operation between the two groups, where farmers in the intervention group demonstrated better understanding of the related topic than the control group ($P < 0.05$, *t* test). A linear regression model indicated that baseline and follow-up scores in both knowledge and practices of the intervention group were higher than those of the control group. After the intervention, the mean difference score in knowledge and practices between the intervention and control groups was 5.0 and 2.0 points, respectively ($P < 0.01$). Therefore, a community-based intervention approach could be applied to improve knowledge and practices among farmers in using biogas systems. However, further studies should be conducted to assess the sustainability and effectiveness of this model (Luu *et al.*, 2018). This biogas intervention was evaluated and shows that the intervention should be collegial to give opportunities for all related stakeholders to build capacity, support, and achieve the transdisciplinary principle. This also helps ensure that the community-based solutions are incorporated in public health interventions. Participatory monitoring and evaluation should support the understanding of the implementation process to capture intervention outcomes (Pham *et al.*, 2018). This implies a significant reduction of estimated annual risk of infections. Therefore, the combined human and animal waste management strategy shows the benefit of financial savings for the treatment option investment, which helps reduce environmental and health risk. The model is currently being promoted in Hanam (Fig. 13.4).

Challenges of chemical contamination in Vietnam

Our research focused mainly on the effects of microbial contamination of human and animal waste on human health and the environment, as this is an

Fig. 13.4. The experimental field model used for combined human and animal waste composting.

important issue in developing countries. However, this is only a facet of the complex environmental sanitation picture. Among other types, large volumes of mixed domestic, hospital and industrial wastewater are discharged into water bodies, and in Vietnam, only about 20% are treated. This presents a threat as groundwater quality contamination, but more importantly for surface water in the peri-urban environment, where this wastewater is used to irrigate crops and flows into aquaculture. The health and environmental impacts include, for example, the accumulation of heavy metals in vegetables and fish fed by wastewater, products which will be further consumed by humans (Fitamo *et al*., 2007). Such high concentrations were observed in morning glory spinach, fish, and water from the To Lich and Nhue rivers and in the river basins within Hanoi and Hanam provinces (Marcussen *et al*., 2008, 2012; Ingvertsen *et al*., 2013).

The whole issue of chemical, soil and groundwater contamination is challenging for the country, as this is driven by economic growth and environmental degradation. Past experience from developed countries with environmental degradation related to the Industrial Revolution provides important lessons for LMICs, including Vietnam. However, these are not sufficiently addressed, as countries like Vietnam and China are experiencing rapid economic growth, with huge impacts on health and the environment. Although balancing economic growth and environmental and health protection are difficult, strong political goodwill along with that from civil society organizations are needed. For this, a One Health approach is useful to bring different people to work effectively together.

Conclusion and the Way Forward

SDG 6 relates to clean water and sanitation and provides new specific targets for some very ambitious goals in the domain. Our field experience with the case study in Vietnam shows that sanitation is clearly a complex issue that requires more than behavioural change and large financial investments. The goal of meeting these targets to improve the health of people, while preserving sustainable environments, is a task that requires the perspectives of multiple sectors and stakeholders. The conceptual framework that informs our research provides the starting point for how to integrate aspects that have traditionally been done separately. It has been applied through asking different research questions about the problem of sanitation that has led us to address the different aspects found in the conceptual framework.

In consideration of the local context, the boundaries of the problem of sanitation are not clear, and research designed to address sanitation must draw its own boundaries for practicality. Within these boundaries, progress to date has been around the empirical data collected, which act as pieces of a puzzle. There remains the challenge of putting these together to obtain a more complete picture. One broad area that remains to be integrated is an assessment of the benefits, in terms of ecological services and economic development, of different methods of recycling excreta and other organic wastes (e.g. composting, biogas and other forms of energy production, and fertilizer use). Excreta need to be evaluated both as a valuable source of energy and nutrients, enhancing environmental health and economic development, and in terms of the risks posed to human and animal health. This would enable policy makers to gain a clearer understanding of the financial gains, and not simply costs, of integrated approaches versus more simplistic treatments assessed only on the basis of improved public health or agricultural gains. Moreover, the challenges with climate change impacts, as expected through extreme events like floods and droughts, should be considered in policy making. A recent study shows that Vietnam is among the countries most affected by climate change, in particular there is the risk of Mekong Delta provinces flooding (Kulp and Strauss, 2019).

Integration can mean many different things. In our case, we refer to the combination of knowledge and perspective of different sectors and stakeholders in such a way that brings about different ways of participating in the problem of interest and processes to uncover knowledge that addresses this (Charron, 2012). In this sense, a One Health approach offers a useful conceptual and operational framework for jointly managing the human and animal waste in developing countries where the reuse and recycling of waste for agriculture is important, which is beneficial to the environment, health and the economy. Sanitation Safety Planning can be an important support to all this (WHO, 2016).

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14 Reaping One Health Benefits through Cross-sectoral Services

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Introduction

Both One Health and ecohealth approaches seek a broader approach and understanding of health that goes beyond the realm of biomedical science (Zinsstag, 2012). This approach includes a more thorough attention to healthcare delivery systems than has previously been the case. The approach also implies and demands a more explicit role for plant health, and hence agriculture, in One Health, an area that has received little attention (Box 14.1). The same is true for soil and rangeland health (Boxes 14.2 and 14.3).

This chapter describes the added value of One Health through synergies created in delivering integrated healthcare services across health sectors. Current integration is weak and in the context of 'One Health' has a limited scope commonly restricted to 'integrated surveillance'. In this chapter we use integration to refer to cross-sectoral healthcare/advisory service delivery, where service needs of communities are identified jointly by at least two health sectors, and cross-sectoral planning identifies ways to reach communities more effectively with targeted and relevant services (Tanner *et al*., 1993; Tugwell *et al*., 2006). Such interventions and services applied in communities include joint monitoring of health outcomes (Schelling and Hattendorf, Chapter 8, this volume) and dissemination of information.

Conceptual models for One Health continue to evolve as theory and practice reveal new insights. We use a One Health 'service delivery model' (Fig. 14.1) to explain the rationale and benefits of a cross-sectoral approach to health service. The model illustrates some of the links, dependencies and interactions between the different health sectors and highlights the important role of plant health, the sector which has received least attention. The model highlights important influences on food security and safety (animal and plant health), for example, and the role of plant health in supporting animal and human health (inner circle). The dashed circle represents joint actions, for example cross-sectoral service delivery, learning and health assessments, while the outer circle depicts environmental influences.

The call for more integrated, cross-sectoral services was fuelled by evidence from a growing, yet still limited, number of initiatives showing that there is potential to gain wider health benefits by integrating services across sectors and disciplines, particularly in rural, low-income settings where services by default are scarce. This chapter assembles experiences from different fields of work to illustrate how these added values can be materialized and some of the challenges that get in the way of progress.

In the first part of this chapter, we describe the general characteristics of service delivery in human, animal and plant health. The focus is on rural areas in low-income countries, where integrated ways to deliver health services have the most potential to benefit people and communities. In the second part, we present examples of services that intersect different health sectors and disciplines. We draw wider lessons on the challenges and opportunities of cross-sectoral services and propose ways to

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Box 14.1. The innate ties between plant health, agriculture and One Health. Adapted from Boa *et al*., 2015.

Agriculture and plant health are intrinsically linked to the health of humans, animals and the environment in many different ways. Food security and food safety rely on healthy plants and sound production systems. Plants provide phyto-medicines, shelter, fibre and a range of vital ecosystems services. Poor plant health management leads to crop losses, accumulation of mycotoxins in food and feed, pesticide poisoning, food contamination and environmental pollution, all of which affect the health of humans, animals and ecosystems (Fletcher *et al*., 2009; Savary *et al*., 2017; Logrieco *et al*., 2018). There is evidence to suggest that some invasive plant species may play a role in malaria transmission by providing shelter for adult mosquitoes (Stone *et al*., 2018). In addition, some plants produce toxins and allergens which, if not handled correctly, make people and animals sick (Breiteneder and Radauer, 2004; Chandrasekhar *et al*., 2012).

Conversely, poor health among farmers negatively influences crop and livestock health and productivity through loss of labour and reallocation of resources for managing crop and animal health (Hawkes and Ruel, 2006). Arsyad *et al.* (2019) demonstrated that low cocoa productivity in West Sulawesi was associated with low household dietary diversity and perceptions that food availability was insufficient. Heavy agricultural workloads and low crop diversity may affect women's capacity to feed their children (Jones *et al*., 2012). Thus, poor health, malnutrition and poverty can quickly lead to a vicious 'downward spiral of livelihood degradation for vulnerable households' (Parker *et al*., 2009).

Despite the burgeoning movements and initiatives on One Health in its widest sense, plant health and agriculture are either missing, embedded in environmental health or limited to specific issues around food safety (mycotoxins, foodborne pathogens and pesticides), as in the case of the 'tripartite initiative' by the Food and Agriculture Organization of the United Nations (FAO), World Organisation for Animal Health (OIE) and World Health Organization (WHO) (FAO *et al*., 2017).

While these aspects demonstrably are of vast importance to public and environmental health and global food supply, there is more to gain by addressing the role of plant health and agriculture more broadly and, notably, embracing a stronger focus on cross-sectoral health care/advisory service delivery that meets the needs of individuals and communities.

move ahead. Integrated surveillance systems and measuring the added values from integrated methods are covered separately in Chapters 9 (Aenishaenslin *et al*.), 10 (Häsler *et al*.) and 31 (Zinsstag *et al*.), this volume.

Health Services in Rural, Low-income Settings

Human health systems service delivery and inequities in health

An equitable human health system aims to deliver quality services to all people, when and where they are needed. Ensuring that interventions reach and benefit the disadvantaged is a major challenge. Effective responses to inequalities in health often require actions outside the health sector such as poverty alleviation or rural development initiatives (Kimani *et al*., 2016). Without an explicit assessment of the impact of population health interventions on health inequalities, policies and public or private programmes run the risk of benefiting only the more privileged and better-off without improving the health of the poor – despite national averages indicating overall improvements. Improving access, coverage and quality of services, particularly primary health care, depends on availability of key resources such as trained professionals and equipment. Improvements also depend on the organization and management of services, the incentives influencing providers and users, and the availability of reliable information (WHO, 2013).

Approximately one-half of the global population lives in rural areas, but these areas are served by only 38% of the total nursing workforce and by less than 25% of the total physician workforce (WHO, 2010). The increased number of people being forced to leave rural zones and live in urban slums leads to emerging health inequities in urban centres. Health service delivery is difficult, in particular due to logistical, organizational and human resources (especially qualified personnel) and

Box 14.2. The earth beneath our feet: the case of soil health and One Health. Contributed by Maxine Whittaker.

The effects of the health of soil upon human, animal and plant health and the effects human and animal activities have upon soil health have been under-addressed in discussions of One Health.

Soil can harbour a wide range of organisms and substances that may cause disease in animals and humans, especially in the tropics. Ingestion of soil (deliberate or accidental) can lead to intake of parasitic eggs such as *Ascaris lumbricoides* and *Trichuris trichiura*. Animals in the environment, for example dogs and cats, can contaminate soil through their faeces and cause toxocariasis infection (roundworms) which can lead to organ and eye diseases, especially in young children who often accidentally eat soil (Abrahams, 2002). Microorganisms can be dispersed through soil and soil dust: *Aspergillus*, *Burkholderia pseudomallei* and *Coccidioides immitis* are all well-known causes of human illness. *Clostridium tetani* is found in surface layers of soil, and in human and animal excreta, and is especially abundant in manured and cultivated fields. Gardeners, farmers, archaeologists, pregnant women and newborn babies delivered on the ground are some of the people at risk. Human infections with hookworms are caused by skin contact with contaminated soil. These infections are extremely common and are exacerbated in areas with poor sanitation facilities and practices. Dermal absorption of abiotic components in the soil (e.g. dioxins, pesticides, polynuclear aromatic hydrocarbons) can also impair animal and human health (Lane *et al*., 2015).

Agriculture is, of course, intimately connected to soil. Soils contain essential elements required for plant health, and hence, animal and human nutrition. However, the balance between healthy and toxic levels can be fragile (e.g. selenium) (Tahir *et al*., 2018). The soil pH, drainage and other factors affect the bioavailability of these elements, and this can be affected by land use changes and climate change. Pesticides deposited on soil can pollute ground and surface waters and harm humans, animals and ecosystems. Antibiotics added to livestock feed can enter the soil and groundwater, and antibiotic-resistant microorganisms have been detected in these sources (Forsberg *et al*., 2012). The soil can also affect the quality of the water moving through the soil – leaching elements like nitrogen, iron, manganese and aluminium into groundwater supplies.

As these examples show, healthy soil – defined by the 'capacity of soil to function as a vital living system to sustain biological productivity, maintain environmental quality, and promote plant, animal, and human health' (Doran *et al*., 1996) – is a critical component of One Health.

Box 14.3. The role of healthy rangelands in One Health. Adapted from Flintan *et al*., 2020.

In the past, although giving attention to the people and the animals in pastoral societies, development interventions, including One Health approaches, usually ignored the rangelands (land and natural resources). Healthy rangelands provide for healthy livestock that provide for healthy people. Well-functioning rangelands sustain the soil, moisture and nutrient availability for plants on which animals feed. At the same time, healthy rangelands also provide a wealth of ecosystem services such as carbon and water storage, prevention of soil erosion, and provision of a generally ameliorating environment that has a direct impact on human and animal health (Riginos *et al*., 2011).

With increasing pressures on land use, there is an urgent need for investment in sustainable rangeland management and restoration. Participatory approaches to rangeland management are now being combined with a One Health approach. This includes establishing community-defined 'One Health units' at strategic points in the rangelands landscape where human, livestock and rangeland health services converge with community needs. Experience is showing that this not only benefits the individual components including rangeland management, but also has combined benefits of rebuilding an integrated system that is more productive as a whole.

financial constraints (and declining public-sector budgets). Loss of confidence by the community as a result of unmet demand should also be mentioned. Increasing numbers of displaced people, mobile, migratory populations and remote rural communities are unable to benefit equally from governmental or private health services, compared with those in urban centres.

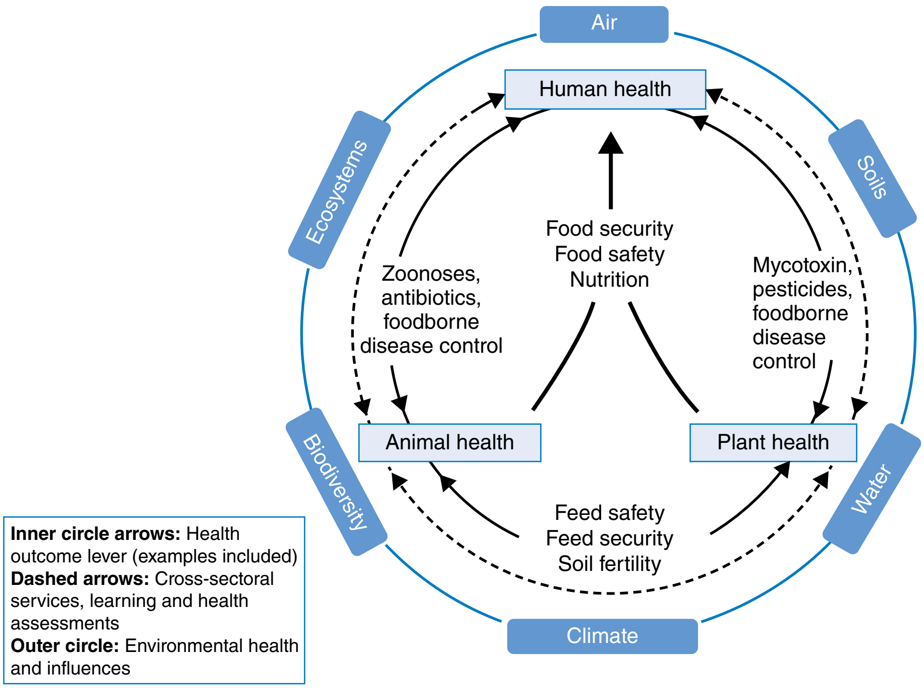

Fig. 14.1. One Health 'service delivery model'. Adapted from Danielsen, 2013.

The WHO recognizes that integrated health services are critical for reaching universal health coverage within the continuum of health promotion, disease prevention, diagnosis, treatment, disease management, rehabilitation and palliative care services. An early example was the combination of measles vaccination campaigns with the distribution of insecticide-treated bed-nets (ITN) in Ghana (Grabowsky *et al.*, 2005). Such integrated approaches should lead to more equity-effective planning (WHO and UNICEF, 2005). Studies show that rather than taking a traditional approach (i.e. initially serving those who are easiest to reach) approaches designed to first increase coverage among disadvantaged groups show most progress towards universal health coverage (Gwatkin and Ergo, 2011). The Sustainable Development Goals' (SDGs) commitment to leave no one behind strongly supports the progressive realization of universal health coverage and the right to health (WHO, 2016).

Veterinary services and rural zones

Highly contagious animal diseases and epidemics pose an economic threat to livestock producers, the entire agricultural sector and national economies. Animal disease control and elimination is therefore considered a public good. Animal health officials worldwide coordinate their disease control strategies with the OIE. Typically, national veterinary services are responsible for ensuring protection of animal health, safety of food products of animal origin and control of major animal diseases, as well as quality control of veterinary pharmaceuticals. Most veterinary services may enforce animal welfare standards, and in some countries, the veterinary service is also responsible for monitoring and controlling wildlife diseases. The latter generally fall under the jurisdiction of environment ministries, whose involvement in wildlife is largely limited to management of parks and related matters concerning biodiversity conservation (Cumming and Cumming, 2015). The 'public good' nature of some services does not necessarily imply that the government must take direct responsibility for their delivery. These services may be subcontracted to private organizations (e.g. non-governmental organizations (NGOs) or research organizations) and private veterinarians.

Animal health systems have been neglected in many parts of the world, leading to institutional weaknesses and information gaps as well as inadequate investments in animal-health-related public goods (Abakar *et al.*, 2019). This is particularly evident in remote and rural zones, where between 46% and 82% of rural households in Asia, Africa and Latin America keep livestock (Zezza *et al.*, 2007).

Vaccination remains a key community-effective health intervention in human and animal health and is increasingly an important tool in wildlife health management. Smallpox and rinderpest eradication programmes benefited from committed financial and personnel investments. There are poliomyelitis-contagious bovine pleuropneumonia (CBPP) and peste des petits ruminants eradication programmes that, among others, need to deal with vaccines requiring a cold chain. This necessitates innovations and adaptation to successfully reach all communities and remaining pockets of disease transmission. The last pockets of rinderpest were among pastoralists, and only participatory approaches allowed for reaching these remote communities (Jost *et al.*, 2007). Development of a thermostable efficacious vaccine was also a huge advantage.

Human and animal health vaccination programmes may experience both periodic lack of vaccination-related supplies and limited or poorly maintained infrastructure in the governmental services. Poor implementation or inferior quality of animal vaccines not only causes economic losses in the livestock sector but can also be a human health threat when vaccines against zoonoses are not efficacious. On the other hand, public health practitioners sometimes envy their veterinary colleagues who have a public-good mandate to vaccinate against epidemic and zoonotic diseases. Veterinary authorities may declare a livestock vaccine as compulsory given the economic and societal interests to better control these diseases. Vaccination programmes rooted in either the public health or the veterinary sector have hardly interacted in the past, despite the fact that they to a large extent target the same populations, those vulnerable to exclusion from any health services.

Veterinarians are not allowed to treat human patients, and paraprofessionals often are not allowed to handle certain human and animal drugs or to perform simple interventions. These restrictions also apply in remote areas, where neither physicians nor veterinarians are available. With a proper legal framework and appropriate training, however, certain public health activities could be shared – for instance, in surveillance. Public health and veterinary programmes should more widely share their knowledge and their different approaches – and explore local priorities and perceived needs. They can then develop joint implementation arrangements to improve services to remote and rural communities.

Plant health services and agricultural extension

Plant health services for farmers are usually provided as part of general agricultural extension services. Most of the 'plant health workforce' comprises agronomists and agricultural technicians who have a broad range of responsibilities. There is some separation between extension workers with responsibilities for crops and livestock, but it is common in many countries for them to give farmers advice on both. There are fewer legal restrictions on the services that agricultural/crop advisers can give compared with veterinary and human health service providers. Subject matter specialists in crop protection do exist, but they are few and usually thinly spread (Boa *et al.*, 2015). Plant diagnostic laboratories provide technical backup, but they are also few and difficult for farmers to access (Smith *et al.*, 2008; Mugambi *et al.*, 2016). Plant health regulation is organized through National Plant Protection Organizations (NPPOs), which are generally restricted to inspecting plants and plant products entering countries. NPPOs also undertake general surveillance and organize responses to pest and disease outbreaks, but provide few if any regular services to deal with farmers' basic crop health problems. A study from Uganda revealed that there is a pervasive feeling among extension organizations and ministry officials that farmers have been abandoned in their struggle against an escalating plant pest and disease burden (Danielsen *et al.*, 2014).

When emerging diseases cause major damage or pose major threats, such as banana bacterial wilt or maize lethal necrotic disease (Anderson *et al.*, 2004), plant health may gain a temporary, but unsustainable, boost in priority and funding allocation. Most low-income countries are poorly prepared to deal with major pest outbreaks as shown in the slow and often ineffective responses to recent outbreaks of fall armyworm and desert locust in East Africa. Farmer services are generally scarce and under-resourced in low-income countries. A recent assessment of extension services in ten African and Asian countries showed an overall low coverage with a ratio of extension agents to farm families varying from 1:1000 to 1:10,000 (Davis and Franzel, 2018).

Inspired by concepts and actions used in human health service delivery (Danielsen *et al*., 2013; Romney *et al*., 2013; Danielsen and Matsiko, 2016), and building on earlier work by the Global Plant Clinic (Bentley *et al*., 2009; Boa, 2009), CABI's Plantwise programme has contributed to fill the gaps in plant health service delivery since 2011. Using a plant health systems approach Plantwise supports establishment of more responsive plant health services for farmers through training of 'plant doctors' (extension workers) in field diagnostics and plant health care and establishment of networks of plant clinics. The idea of plant doctors is not new (Large, 1940). Currently, 11 universities in the USA (in Florida, Nebraska and Ohio) and Asia (Japan, South Korea and Taiwan) provide training for plant health professionals to become plant doctors, and more are joining (McGovern and To-anun, 2016) Yet, compared with the well-established professional staff categories in human and animal health, plant health lags far behind. Over 10,000 extension workers have been trained as 'plant doctors' in more than 30 countries across Africa, Asia and the Americas under the Plantwise programme (David *et al*., 2019), yet the plant doctor title has not yet been formalized in any of these countries.

The delivery of plant health care (e.g. through plant clinics) is still in its infancy and far from mainstream practice in agricultural advisory services. Organizational change is slow and constrained by institutional and capacity barriers. Yet, the recent surge in availability and access to digital tools has opened up new opportunities to connect people and services, making extension services and countries more responsive, both to farmers' daily needs for plant health advice and information and when major epidemics emerge (David *et al*., 2019; Tambo *et al*., 2019). Plant clinics also have a role to play in human, animal and environmental health, as plant doctors give advice on safe use of pesticides and postharvest management to reduce mycotoxin levels. Recent studies show promising results regarding the impact of plant clinics on pesticide use, crop yields, household income and resilience (Musebe *et al*., 2018; Silvestri *et al*., 2019; Tambo *et al*., 2020).

Cross-sectoral Services in Practice: Five Case Illustrations

Cross-sectoral services are still relatively rare, though there is a growing body of evidence that shows their value and relevance, as well as some operational challenges related to delivery of services that transect sectors and disciplines. The following cases represent experiences and lessons learned to illustrate this.

Case 1. Cross-sectoral learning – community and service provider perspectives

Communities often demand more health information. One Health services can play a role in providing appropriate health information in rural zones. People who work with animals may understand human health concepts better when linked to their experiential knowledge of animal health and diseases. Health messages that are disseminated in information, education and communication (IEC) and social marketing approaches should be adapted to the cultural background and accommodate the levels of illiteracy of rural communities. How to produce effective health communications and social marketing is generally understood (Maibach *et al*., 2007) but is often not done in remote settings because of resourcing or concerns about how to provide understandable concepts to low-literacy populations. Effective ethno-medical practices and traditional health-care networks could be an integral part of such delivery systems and be sensitive to avoid subordinating traditional medicine to the modern medical sector (McCorkle, 1996; Hitziger *et al*., 2018).

Community health and community animal health workers largely provide primary health care in remote zones (Vétérinaires sans Frontières International, 2018). The advantage of community workers is that they are more accessible to community members who may face difficulties to access services situated further away. We believe that all possible actors, including strong producer organizations and farmer cooperatives, informal and traditional health sectors and NGOs, should be included to identify opportunities for closer cooperation in adapted information delivery which may lead to synergies. An example of cross-sectoral learning is shown in Box 14.4.

Box 14.4. Cross-sectoral learning and health assessment. Adapted from Boa *et al.*, 2015.

An ecohealth approach was used in Ecuador to address rampant health problems in plants (Andean weevil and late blight) and humans (high incidence of pesticide poisoning). Even though the health outcomes were less than expected, the study confirmed the validity of cross-sectoral actions. The study also provided important lessons for future similar approaches concerning other aspects of plant and human health (Yanggen *et al*., 2004; Zinsstag *et al*., 2011).

Two FAO studies in Africa looked at emerging and re-emerging diseases of agricultural importance in all three health sectors in two locations, one on the border of Tanzania and Uganda (Rugalema and Mathieson, 2009), the other between Malawi and Mozambique (Bentley *et al*., 2012). They considered the combined impact of plant, human and animal diseases from a broad livelihood perspective. A separate paper from the larger Tanzania/Uganda study looked at local perceptions of disease and why recommended control measures and strategies were often ignored (Rugalema *et al*., 2009). One of the overall conclusions was that a lack of professional collaboration between health professionals undermined attempts to limit the knock-on effect of diseases in other sectors. Most residents in the border region between Malawi and Mozambique crossed frequently and were 'rarely empty-handed, often taking plants and animals'. The studies said that it was better to share information about diseases occurring on both sides of the border, rather than attempt to limit travel and hinder trade that depended on plants and animals (Bentley *et al*., 2012). These initial insights confirm the need to continue using a cross-sectoral approach to understand and minimize the human, animal and plant health risks associated with movement of people across borders.

Case 2. Joint human and animal health delivery services

Based on findings of a simultaneous assessment of human and animal health service needs in Chad, a broad agreement was reached with national and local authorities as well as communities to test joint human and animal vaccination services (Schelling *et al*., 2008). Together with authorities, such joint vaccination campaigns were evaluated from 2000 through to 2005 and showed the feasibility of combining vaccination programmes for mobile pastoralists and their livestock. Sharing transport logistics and equipment between physicians and veterinarians reduced total costs (15% of the public health sector) (Schelling *et al*., 2007, 2015). Agronomes et Vétérinaires sans Frontières, who faced difficulties with absent private veterinarians, facilitated joint health delivery systems in Niger and Mali (AVSF, 2010).

These joint campaigns also helped improve understanding of how to set up a system that alternates between mobile and static health services, and how to make static services more responsive to receive members of communities who are only temporarily in their zones of responsibility (Lechthaler *et al*., 2018). Currently, there are evaluations on many other services beyond information and vaccination such as antenatal care, distribution of bed-nets, etc., which can be grafted in to these campaigns to benefit from shared interests, and shared human and logistical resources. The margins of adding many other services to core cross-sectoral services are narrow. Quite quickly two vehicles are needed – one for veterinary and one for public health staff – and the effects of cost sharing are virtually extinguished – leaving only provision of cross-sectoral information remaining. Wanting joint service provision to be 'all inclusive' cannot be the goal – it should instead be focused on the main community priorities, such as rabies and soil-transmitted helminths (Lankester *et al*., 2019).

Case 3. Emerging demand for crop-livestock clinics

There are an estimated 570 million small farms (< 2 ha) worldwide, more than 85% of which are in Asia and Africa (Lowder *et al*., 2016). Plants serve as feed for animals and food for humans in mixed crop-livestock smallholder production systems (Wright *et al*., 2012).

CABI's work with plant clinics over the last 15 years (see section on 'Plant health services and agricultural extension') has revealed potential 'One Health benefits' of broadening their scope to better meet farmers' demands for advice. Emerging synergies were first noted in Nicaragua, Bangladesh and

Uganda around 2005–2007 where plant clinics informally began to respond to farmer requests for advice on livestock (Danielsen, 2013). One plant clinic in Peru took it a step further and turned the clinic into a 'crop and livestock clinic' because as one of the plant doctors said: 'We always receive livestock and crop queries in the plant clinic. We receive many queries for problems which are common here for guinea pigs and cattle, for example problems with ectoparasites and flies. We try to respond as best we can' (Danielsen, 2017).

To better understand the nature of the livestock queries presented at plant clinics, a survey was carried out among 180 plant doctors from Uganda, Kenya, Zambia, Peru and Costa Rica (Danielsen *et al*., 2019). Over 80% of the plant doctors replied that they regularly receive queries from farmers on livestock topics: half on disease issues and half on animal husbandry. The answers were almost equally divided between plant doctors who gave advice and those who referred to someone else. On some occasions, animal advice was delivered by livestock specialists participating in the plant clinic sessions. Most of the plant doctors (70%) would like to formally integrate an animal advisory service into the plant clinics to better respond to farmer needs. For many extension workers, the crop–livestock connection is obvious and already part of their work. However, they also recognize the challenges involved and the need for technical backstopping. As one plant doctor said: 'I gave some basic advice on hygiene and fodder production, but in most cases I refer them to veterinary and livestock officers.'

This example shows that the single sector approach to service delivery often does not fulfil small-scale farmer needs in mixed farming areas. Rural families do not divide their livelihood issues neatly into subject matter or discipline. Plant clinics inadvertently became a mechanism for capturing farmer demand for information and advice more broadly. Joint service delivery has the potential to meet some of the unmet demand by making better use of existing resources and capacities.

Plans are underway to explore how, and with what capacity and support, such 'crop–livestock clinics' could function more formally within existing legal and institutional structures. The human health sector should also be brought into the conversations to shape the intervention towards maximizing human health outcomes through, for example, better zoonosis control and improved hygiene, thus contributing to the health and livelihoods of rural communities. However, as stated in Case 2, pragmatic solutions addressing the most urgent health needs of the communities must be tackled in a way that does not overload the cross-sectoral services (Berger-González *et al*., Chapter 6, this volume). Otherwise, the added value in terms of saving human and logistical resources could quickly be undermined.

Case 4. Integration of human and environmental health services

In Madagascar in the early 1990s, in response to lack of access to both health and environmental/agricultural extension services and lack of family planning services in conservation zones, different groups began experimenting with joint population, health and environmental initiatives. By the late 1990s, implementation strategies from both the environmental and health sectors supported joint activities such as social marketing. By focusing on small, achievable actions at the community level, the population, health and environmental (PHE) movement began to grow. Activities were implemented by local health and environment NGOs and a strategy of 'Champion Communities' was adopted in four of the six provinces in Madagascar. By 2005, a national consortium with 29 member groups was formed to link PHE efforts. Progress was measured by local monitoring that tracked the increased use of essential health services. Key health indicators and land-use practices have improved over a 3-year period among integrated compared to non-integrated communities. Use of preventive health services such as vaccination and modern family planning, home-based prevention measures (e.g. use of ITNs) as well as participation in reforestation efforts and vector control increased in PHE project zones, surpassing national norms. In addition, malnutrition prevalence dropped, and access to safe water improved (Ribaira and Rossi, 2007).

Synergies between sectors manifested themselves in improved capacity at the programme and organizational levels and in the communities' progress towards self-determined and sustainable development. The integrated approach resulted in greater effectiveness of interventions and achieved relatively better outcomes for low incremental costs compared with single-sector vertical approaches (Kleinau *et al*., 2005). The PHE programme serves as a flagship example of integrating health, population and environment services (Kleinau *et al.*, 2005; Gaffikin *et al.*, 2007). This programme combining health and environment services has similar goals, evaluation approaches and conclusions to the good practices described for delivery of health services to low-income populations (Schelling *et al.*, 2009).

Case 5. 'Tripartite' actions: intentions and realities

A study from Uganda demonstrated the potential for integrating health services around 'village health teams' as a single 'tripartite' point where human, animal and plant health issues can be referred (Haesen, 2013; see the 'service delivery model' in Fig. 14.1). Although all delivery systems were found to have similar challenges in paying staff and ensuring effective referrals, district officers across sectors identified clear opportunities for human, animal and plant health to work more closely together. The existing organizational structures within the three sectors arguably would allow for better coordination of community health services.

Rapid developments in digital platforms, tools and devices provide opportunities for information delivery and sharing across sectors. For example, Infonet Biovision[1] provides online and offline scientific and practical validated information related to plant (crop), animal, human and environmental health. Similarly, human, animal and plant diseases are all covered by ProMed-mail,[2] an internet-based reporting system for 'rapid global dissemination of information on outbreaks of human, animal and plant infectious diseases and acute exposures to toxins'. Run by the International Society for Infectious Diseases, alerts are issued on diseases affecting people, animals and plants.

In other cases, the embedding of plant health in 'tripartite' actions is thornier. Joint actions in diagnostics would appear to be relatively straightforward since similar methods are used to identify human, animal and plant pathogens, such as lateral flow devices (see Fletcher *et al.*, 2009 for in-depth review). Human and animal pathology services already collaborate in confirming zoonotic diseases, although there is further scope for sharing facilities (Zinsstag *et al.*, 2005). Yet, disciplinary boundaries and institutional barriers remain for including plants as well. A mid-term review of the UK government Foresight project on detection and identification of infectious diseases pointed out the challenges of including plants:

> The intention of the Project to incorporate plants into the cross-sectoral collaboration on infectious disease detection, identification and surveillance has occurred only in a limited fashion, most notably the Defra 'BioChip' project [development of a micro-assay to detect viruses in humans, animals and plants]. … The intention to more closely link the medical/veterinary disease research with that of plant disease research did not materialise to any lasting extent. … This largely reflects the close relationship between the human/animal pathogens and the lack of related plant pathogens, even though the technologies have much in common.
>
> (Foresight, 2014, p. 22)

Status and Ways Forward with Cross-sectoral Services

Over the last two decades, One Health thinking and action has stimulated new ideas about a broader vision of health and encouraged transdisciplinary research that examines the complexity of interactions between people, animals, plants and their surroundings (Boa *et al.*, 2015). More important than theory is that for the communities, One Health considers co-benefits and co-challenges so that solutions with multiple bottom lines can be achieved, whether they are for humans, animals, plants or ecosystems (Dominguez-Salas *et al.*, 2019).

Service delivery in human, animal and plant health has common features as well as differences. What works in one sector could work in another; opportunities exist for combining services in different 'dual' or 'tripartite' ways. Considering the underlying call of the SDGs to 'leave no one behind', the three services face similar problems: how to provide (extension) services to those who are geographically or culturally furthest away from services.

The examples shown here emerged from different starting points. Some cross-sectoral interventions were motivated by the prospect of enhancing the reach of services in resource-poor rural areas through sharing of costs and staff, as in the case of joint vaccination campaigns (Case 2) and crop-livestock clinics (Case 3). These actions soon revealed that there is more to gain from the emerging synergies in terms of learning, raising awareness, and health and productivity outcomes. Other interventions sought to solve human health problems generated in agriculture (i.e. pesticide poisoning) (Box 14.4), and still others used community mobilization to address prevalent human and environmental health issues (Case 4).

There is a seemingly high potential in rural low-income areas to combine health services for joint delivery of human and animal health, plant and environmental care. Cross-sectoral health services have become noticeable examples of the added value of One Health (Schelling *et al.*, 2009; The World Bank, 2010; Danielsen *et al.*, 2019) (Zinsstag *et al.*, Chapter 31, this volume). Nonetheless, changes in service delivery systems are the exception rather than the rule and often result from time-bound projects rather than fundamental organizational changes.

There are a number of common barriers that obstruct progress. Some of these are imposed by the bureaucratic division of responsibility and financial flows (disparities in sector funding) between institutions and ministries. Others relate to budgetary constraints, unequal institutional capabilities and differing cultures, limited inter-institutional communication, absence of a shared vision and disincentives to work more horizontally (Schelling *et al.*, 2007; The World Bank, 2010; Braun *et al.*, 2012). However, much progress has been achieved in the last decade. New cross-sectoral services are being tested, and new evidence on their benefits is growing fast.

A unified vision of health and health care is a powerful concept for tackling the complex challenges implicit in the SDGs. Creating cross-sectoral collaborations will require institutional innovation, careful testing of assumptions, as well as new methods and metrics for assessing jointly agreed outcomes, if such novel approaches are to bring about demonstrable and lasting change. Essentially, which is important to note, cross-sectoral services cannot serve all prevailing health issues concurrently. In fact, many are not perceived as such by the communities. The communities should themselves be empowered to state which mix of priority services they want for their community.

Based on the experiences described above, we recommend the following:

1. The inclusion of different stakeholders in the conceptual and planning phase is crucial, as it increases ownership among the concerned populations and authorities. The communities should be empowered to be decision makers to define the 'One Health services' they want.

2. Incentives for collaboration and resource sharing could be created. For example, budget lines could be shared between different agencies, directed by the Ministry of Finance. Services should demonstrate that they truly share resources and not only state that they use a One Health approach to access new funding schemes – which is against the initial thinking of 'One Health services'.

3. Equity analyses based on the geographical deployment of new programmes and strategies can help assess whether programmes are reaching those who need them most.

4. As much as possible, one must avoid establishing new parallel structures and instead make use of existing systems, infrastructure and human resources that are well linked in to the service provision systems of their countries.

5. The evaluation of community effectiveness should be designed and carried out with multiple stakeholders, including communities, national and local services, international organizations and standards.

6. Health systems and traditional institutional arrangements must be carefully examined to identify opportunities to join public health, veterinary, agricultural and environmental services. Case studies and demonstration of feasibility and outcomes are recommended before gradual expansion to other zones.

Notes

[1] Available at: https://www.infonet-biovision.org/ (accessed 27 March 2020).

[2] Available at: https://promedmail.org/ (accessed 27 March 2020).

Acknowledgements

Preparation of this chapter was supported by the Plantwise programme of CABI, which is financed by the UK Department for International Development, the Swiss Agency for Development and Cooperation, the European Union, the Directorate-General for International Cooperation of the Netherlands, the Australian Centre for International Agricultural Research, the Ministry of Agriculture of the People's Republic of China, Irish Aid, and the International Fund for Agricultural Development.

Additional funds were provided by the Swiss National Science Foundation, Lotteriefonds beider Basel and the OPTIMUS Foundation.

Thank you to Eric Boa for valuable comments and edits to the manuscript.

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15 One Health Leadership and Team Building Training

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Introduction

A primary role of leaders in One Health (OH) is to bring 'stakeholders together to identify shared interests and reach consensus about actions to address grand challenges' (Hueston *et al.*, 2018). As a result, a wide range of unique multisectoral skill sets are needed in OH leadership. The successful application of leadership skills and competencies involved with managing OH challenges must lead to the implementation of effective teams and collaborations and thus superior performance in the overall multisectoral response to OH issues. Therefore, understanding and deploying field-validated OH leadership competencies in practice can lead to the successful training of future leaders (Brownwell and Goldsmith, 2006).

Previous studies have evaluated the competencies needed to operationalize the OH approach (Frankson *et al.*, 2016; Hueston *et al.*, 2018; Togami *et al.*, 2018; Amuguni *et al.*, 2019). Based on a review of core competencies in these papers and those used in academic degree programmes, leadership is often one of the major core competency domains for OH (Frankson *et al.*, 2016; Togami *et al.*, 2018). Furthermore, leadership has been included in global and regional core competency lists (Amuguni *et al.*, 2019). Specific to OH leadership, the critical competencies proposed by Hueston *et al.* (2018) include teamwork, interpersonal skills (self-awareness, emotional intelligence, communications, facilitation) and critical thinking (systems thinking, strategic thinking). Yet, information on what leadership competencies have actually been used in the real-world training of future OH leaders has not been discussed, and this chapter seeks to address this gap.

In this chapter, we present five case studies on OH leadership and team building programmes and approaches and then compare them to determine what competencies they are emphasizing as critical in their cultural and operational context. Case studies were selected to represent OH leadership and team building programmes within country and regional contexts. The cases discussed include the: (i) Global Health True Leaders (GHTL) programme in Indonesia; (ii) International Master of Public Health OH-oriented programme at Hanoi Medical University (HMU) in Vietnam; (iii) Engaging Intergovernmental Organizations (EIO) program at the University of Minnesota in the USA;

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(iv) One Health Systems Mapping and Analysis Resource Toolkit (OH-SMART™), implemented in 18 countries; and (v) multidisciplinary OH field attachments/placement programmes implemented by the One Health Central and Eastern Africa (OHCEA) university network in eight countries. All of these programmes were supported, in part, by the USAID One Health Workforce (OHW) Project. In presenting and analysing these case studies, this chapter provides examples of five field-validated programmes involving OH leadership and what competencies they identified as critical to OH leadership in their context.

Case 1: Global Health True Leaders (GHTL)

GHTL is a leadership training programme that focuses on establishing and improving collaboration among young interdisciplinary health and health-related students/professionals to address global health issues. The main objective of GHTL is to coordinate, collaborate and lead a multisectoral workforce team to prevent, detect and respond to emerging global health and OH threats. In terms of leadership skills, this programme places an emphasis on working across disciplines, team building, communication, consensus building, cultural competency and collaboration. This is a strategic investment to promote multidisciplinary work in an OH workforce from different professions, different sectors and different levels of society (local to international). GHTL was first introduced in 2014. To date, it has produced 11 cohorts with over 575 alumni from Indonesia, Malaysia, Vietnam, Thailand, the Philippines, Lao People's Democratic Republic, Cambodia, China, Nepal and Myanmar. In each training, the GHTL theme and approach were tailored to conform to the local culture where the training was conducted. This method was used to emphasize the importance of culture and local wisdom in the OH approach.

The goal of the GHTP is for participants to understand the importance of collaborative work to address OH problems, particularly through hands-on teamwork, field-based simulations and community engagement. GHTL was designed to uphold three key values: (i) leadership; (ii) collaboration; and (iii) youth movement. The programme prepares participants to work with the community and conduct field interventions in a culturally appropriate way that acknowledges and builds on the community's unique cultural beliefs, practices and needs. Through simulations, participants practice the leadership and OH communication skills they learned during the in-class sessions. The participants indicated that these field simulations and community sessions provided an opportunity to practise their skills, to understand how to collaborate with OH stakeholders, and to communicate to target audiences. It also helped them to build OH skills to analyse complex situations and to determine appropriate strategies to address OH problems.

Throughout the training and during fieldwork, participants take on diverse roles in their assigned team to build skills in teamwork and leadership. They also gain practical, real-world experience to engage and empower their community stakeholders in culturally appropriate ways.

Design and structure of the programme

The programme was developed and implemented by the Indonesia One Health University Network (INDOHUN). The training was designed for undergraduate and graduate students as well as young professionals in health-related fields. The GHTL training runs for 5–6 days including 4 days of in-class training and 1–2 days in a designated village. GHTL has different themes that provide understanding in global health challenges and support skill building in OH concepts, epidemiology, leadership, communication, public speaking, collaboration, public policy and advocacy.

The sustainability of GHTL has relied on funding and support from international and national partners including the United States Agency for International Development (USAID), International Development Research Centre (IDRC), the Indonesian Army, the University of Minnesota (UMN), the government of Indonesia (at district and central levels), Streleix Strategy Management Inc., Tufts University, OHCEA, the Southeast Asia One Health University Network (SEAOHUN), and INDOHUN member universities. This programme continues to grow and has added new partners, contributing to the long-term resilience of the programme.

Programme leadership training attributes

Participants were assessed on their performance, interaction and knowledge during and after training, using three evaluation strategies:

1. A daily performance evaluation was completed by facilitators who were assigned to moderate the training exercises. There were seven points of assessment that covered three soft skills (teamwork, leadership and performance).

2. A daily assessment report was completed by participants. There were questions exploring what they learned that day, what leadership values they gained and what topic they found most difficult.

3. A participant survey was completed by participants to gather opinions and feedback about the training. There were two sections in the survey: (i) quality and organization of the training; and (ii) personal and professional relevance.

Results of these evaluations indicate that GHTL helped participants expand their network and improved their leadership, public-speaking skills, and their understanding of the importance of collaboration and applying the OH approach in tackling problems. GHTL provided an opportunity for young members of the present and future workforce to gather and unite to exchange ideas and come up with solutions for practical OH issues in their community. Furthermore, previous programme cohorts supported subsequent groups as volunteers, providing mentoring through content expertise and experience, which also created programme continuity. Evaluations indicated that the diversity of participants' cultural and disciplinary background supported increased cultural awareness, contributing to ongoing community-level engagement.

As a result of the success of GHTL, INDOHUN launched the Global Health Leaders Alliance (GHLA) to support current and future trainees in 2018. GHLA serves as an ongoing platform to gather GHTL alumni and connect them with other global health leaders regionally.

GHTL inspires young OH leaders to strive towards their goals of leading and facilitating collaborative work. As a result, some programme alumni initiated collaborative work with the Indonesia Conservation Community to detect and identify novel viruses in Indonesian wildlife. One young GHTL leader trainee who served as a facilitator is now coordinating and facilitating multi-ministerial efforts as an employee of the Ministry for Human Development and Cultural Affairs (Kemenko PMK). These examples highlight the important role of GHTL in training future OH workers.

Case 2: International Master of Public Health: OH Oriented

The HMU International Master of Public Health with an emphasis on OH approaches is a collaborative effort initially supported by the USAID One Health Workforce (OHW) project. The objective of this programme is to strengthen the capacity of the OH workforce to respond to global health challenges. Graduates are equipped with the skills needed to raise their professional profile, apply different perspectives to address varied public health issues, and participate in global conversations about timely health issues.

The training programme and teaching materials were developed and reviewed by HMU faculty and international experts. Teaching materials were designed in accordance with existing Vietnamese education standards and adapted to international public health requirements with an aim to reflect both local and global contexts. Teaching materials were collaboratively developed and reviewed by a multidisciplinary team. Once finalized, reviews were conducted to adapt and ensure an ideal teaching model for a national and international audience.

Design and structure of the programme

Each year, a cohort of domestic and international students are competitively selected. Within 1 year, students are required to take seven compulsory courses, three elective courses, and complete a final thesis to fulfill graduation requirements. The programme covers foundational topics including: biostatistics, environmental health, global health, health management and policy, applied epidemiology, health education and health promotion, research methodology and public health ethics. Additional specialty courses in health economics, nutrition and food safety, and population and health are offered. The OH approach is incorporated into all of the lectures and case studies to ensure students have the technical, communication and collaboration skills and tools to respond to a public health threat.

Mixed teaching methods are applied with students attending in-class lectures, group discussions and seminar sessions. Courses are led by the Vietnamese faculty with support from international experts to provide a broad learning experience for students. Students practise their critical thinking and soft skills in a classroom setting while also having the opportunity to attend scientific workshops and conduct fieldwork on important OH issues. Through these exercises they identify OH-related approaches and propose collaborative solutions. Through their final thesis, students hone their OH skills while pursuing topics of interest.

Programme leadership training attributes

Evaluation of student performance is by: (i) in-class group discussion; (ii) final course examinations; and (iii) oral defence of their thesis. Students are required to pass all courses and the final thesis defence to receive their certificate. Assessment of the programme is conducted based on two measures: (i) a course assessment form, completed by students after each course; and (ii) an annual multidisciplinary faculty workshop to review the entire programme and the outcomes of the assessments to adjust the materials and teaching methods based on feedback.

As of 2019, HMU has enrolled three cohorts into the OH International Master of Public Health programme with a total of 60 students from more than a dozen countries including from Asia (Cambodia, Indonesia, Thailand, Vietnam), Africa (Ghana, Liberia, Tanzania, Kenya, Zimbabwe, Uganda, Cameroon, Ethiopia) and North America (USA).

This programme continues to grow and develop a reputation as a country leader in education and training. From word of mouth and the quality of the graduates, many international students, especially those from Africa, continue to apply to the programme. This OH model through HMU is cost-effective and helps students achieve optimal OH learning outcomes. Continued review and improvement of the curriculum promises to support the leadership training of global public health officials. The programme is preparing for international public health programme accreditation.

Case 3: Engaging Intergovernmental Organizations (EIO)

The UMN Center for Animal Health and Food Safety (CAHFS), in collaboration with the Humphrey School of Public Affairs, relaunched the EIO program in March 2019, a programme first offered over 11 years ago, but which lapsed due to leadership turnover. The week-long leadership programme takes participants to Paris, Geneva and Rome, where they visit the headquarters of four primary intergovernmental organizations: (i) the World Organisation of Animal Health (OIE); (ii) the World Health Organization (WHO); (iii) the World Trade Organization (WTO); and (iv) the Food and Agriculture Organization of the United Nations (FAO). During the 2018 programme, the 18 professionals included university faculty members, government officials and intergovernmental employees. Participants were nominated by university or organizational leadership and represented multiple disciplines including policy, medicine, nursing, public health, animal health, environmental health, economics and business. Together, they brought an OH perspective to antimicrobial resistance, food safety, zoonotic diseases and international trade, among other OH challenges.

The programme was led and facilitated by university faculty members from CAHFS, in partnership with leadership at the UMN Humphrey School of Public Affairs, ensuring that programme design and implementation was inherently interdisciplinary. The programme benefited from high-level engagement and participation from the CAHFS Director and the Associate Dean of Research at the Humphrey School of Public Affairs. Their communication ensured that the programme was supported by UMN leadership within interdisciplinary and university-spanning offices such as the Office of the Vice President for Research and the Global Programs Strategy Alliance. As a result, UMN provided a US$10,000 seed grant to support continued collaborative outputs and outcomes from the week-long engagement.

Design and structure of the programme

The multisectoral approach to programme design and curriculum development ensured that participants could network among key global leaders while learning and practising new skills for effective OH collaboration between the private, academic and intergovernmental organizational sectors. Participants were organized into three interdisciplinary 'innovation teams' during the programme and worked jointly through a series of follow-up meetings to submit proposals on current topics, including emerging infectious diseases, antimicrobial use and resistance, and food safety and security. The seed grant ensured that new insights and knowledge were put into action through an innovative programme idea. In the end, the US$10,000 grant was awarded to one collaborative proposal supported by the full EIO 2019 team, led by faculty members from the School of Nursing, School of Public Affairs and CAHFS. The project, entitled 'Partnering for Resilient Communities: Sustainable Global Demonstrations Sites', aimed to strengthen research and partnerships with global researchers through the development of community-led field sites. Grant recipients will work directly with communities in East Africa, Latin America or South-east Asia through these field sites to foster long-term, collaborative projects among regional faculty members, practitioners, and students within the UMN faculty. As global players in international capacity building, faculty members will be able to use their skills to have a tangible impact on the world and link their work to greater international policies and frameworks put forth by the WHO, OIE, FAO and WTO. Feedback from participants indicates the value of the EIO program, for example see Box 15.1.

The EIO program provided a unique opportunity to bring multidisciplinary participants together to innovate around grand challenge issues, ultimately supporting intergovernmental organizations in their mandate to build health and security in member countries. In order to foster meaningful engagement with visited intergovernmental organizations, participants supported two primary outputs: (i) the development of a policy communique, a two-page policy communication that summarized key priorities as shared across all four organizations (OIE, WHO, WTO and FAO), while pointing to potential target innovations that could support national capacity; and (ii) the development of an EIO Grand Challenge Seed Grant, a US$10,000 seed grant provided to spur multidisciplinary teams to collaborate and innovate around intergovernmental organization priority needs identified in the policy communique.

The training objectives were designed to support participants to:

1. Synthesize high priority OH issues and programmatic needs as they exist across all four intergovernmental organizations visited.

> **Box 15.1.** Positive feedback from a participant in the 2019 EIO program.
>
> 'A program like EIO is important because it has helped me "connect the dots" regarding the activities we implement as the OHCEA network,' said Irene Naigaga, DVM, PhD, a participant of the 2019 programme and regional programme manager of OHCEA. 'Coming to this training and having this experience has helped me appreciate the relevance of the work we do at the national and regional level in informing the frameworks at the global level.'

2. Articulate how the intergovernmental organizations interact with each other and with external partners to advance global policies and frameworks.
3. Situate their professional work within the context of international capacity-building efforts and national and subnational structures for global health.
4. Develop a multidisciplinary/sectoral proposal for collaborative work that advances intergovernmental organization policy goals and articulated needs.
5. Communicate and translate science and research for international policy making and programme implementation.

The primary programmatic outcome was intended to result in long-term strategic partnerships and to advance tripartite (WHO, OIE and FAO) initiatives and WTO capacity-building goals. Following the programme, CAHFS recognized the opportunity for universities to provide necessary research and capacity-building support to WHO, OIE, FAO and WTO, and as a result, created a website where staff could submit ideas. New ideas have already been submitted through this website.

The programme has evolved significantly over 11 years, moving from a primary lecture-based programme to facilitated case-based discussions between lecturers, participants and stakeholders. Its successes lie in foundational principles of engaged and collaborative leadership. Collaborative leadership recognizes that complex challenges require engagement across organizational and functional boundaries, while maintaining a sense of shared ownership over end results (Rubin, 2009). Some of the important programme successes lie within the programme's ability to: (i) be multidisciplinary in design; (ii) engage high-level leadership and programme support from the beginning; and (iii) provide multiple avenues for sharing ideas and fostering multidisciplinary engagement at the beginning, middle and end of the programme. This partnership ensures that both social and natural sciences were considered when constructing programme objectives and associated design elements. By having high-level leadership involved from the beginning, leaders were able to mobilize support and encourage strategic participation from across multiple disciplines. This added visibility to the programme and ensured that participants were selected strategically for interest in interdisciplinary work and were well supported. In addition, this support from leadership resulted in the seed grant, allowing tangible collaboration to continue beyond the week-long programme. Finally, each participant was supported to have a voice in their own discipline and then asked to integrate that into larger discussions that are inherently complex and multidisciplinary. Because these conversations were fostered during meetings and presentations, participants were encouraged to synthesize their ideas quickly for diverse audiences. In addition, the programme supported the use of the WhatsApp™ popular messaging platform for continual sharing of ideas, which allowed people to contribute in their own time, or as ideas arose later during the course of the programme. These WhatsApp™ discussions then set the stage for debrief meetings after the programme that provided the necessary time to integrate and synthesize knowledge into areas where participants were already active. This allowed them to leverage resources, skillsets and new proposals more effectively. The platforms also allowed programme leaders to capture outputs and outcomes of the programme. The use of these communication platforms in turn both directly resulted in improved leadership competence and also provided ongoing and adaptive collaboration during the programme. Participants were evaluated at 6 months and 1 year post-programme to assess new partnerships and collaborations that resulted from programme engagement.

Case 4: One Health Systems Mapping and Analysis Resource Toolkit (OH-SMART™)

The increasing complexity in health challenges at the human, animal and environmental interface globally is encouraging countries and institutions to embrace an OH approach to more effectively address emerging threats. Despite the increased interest and willingness to adopt OH, the capacity to implement is variable and thus there is a great need for systematic approaches (Bunch and Waltner-Toews, Chapter 4, this volume) to identify existing gaps in these OH systems and develop the leadership and strategies to address them.

Design and structure of the programme

The OH-SMART was developed by UMN and the United States Department of Agriculture (USDA) as an assessment, action planning and prioritization tool designed to map and analyse complex OH challenges such as zoonotic disease outbreaks (before- or after-action plans), antimicrobial resistance, and country workforce planning using a multi-stakeholder approach. The OH-SMART process integrates business process improvement and infrastructure assessment techniques with participatory leadership and facilitation skills. It adapts 'swim lane' system process mapping – a graphical summary of an organization or network's workflow – to highlight the OH interactions between different organizations and individuals and roles played by each. This is combined with other tools to form an operational, stepwise, practical suite of tools. The six unique steps/tools that constitute this process are: (i) stakeholder network identification (Berger-González *et al.*, Chapter 6, this volume); (ii) stakeholder interviews; (iii) map the system; (iv) analyse the system; (v) identify improvement opportunities; and (vi) develop an action plan. The key to success of the tool has been the training of local OH-SMART facilitators in every country where it has been implemented. These facilitators are also trained in key aspects of OH leadership including self-awareness, cultural awareness, use of the OH-SMART tool to improve coordination and enhance collaboration, and use of negotiation and communication skills to achieve shared vision and action in diverse teams/organizations/systems. Following this training, these local facilitators (OH leaders) are then able to implement the tool not only for the initial use of the tool, but later assessments have shown that they often use the toolkit in whole or in parts for promoting and strengthening OH work more generally in their own countries (Errecaborde *et al.*, 2017; Machalaba *et al.*, 2018; Olam *et al.*, 2018; Vesterinen *et al.*, 2019).

The unique blend of tools and skills imparted by OH-SMART has allowed governments, country coordination platforms, and national and local organizations to: (i) enhance OH collaboration through institutionalized avenues that promote the development of flexible teams across their organizations; (ii) identify practical and targeted interventions at specific multisectoral critical control points across their systems; and (iii) train OH leaders as OH-SMART master facilitators to provide a suite of tools for continued stakeholder engagement, advocacy and collaboration (Pelican *et al.*, 2019).

The OH-SMART process is designed to be experiential and is aimed at improving collaboration and operationalization of the multisectoral OH system. Participants are drawn from diverse backgrounds, at a minimum from public health, animal health and environmental health agencies, selected based on their subject area expertise and their potential experience implementing OH within their jurisdiction. The trainers/facilitators normally work with participants to develop an initial, agency-specific map of how multiple agencies are currently interacting to address a given challenge or OH scenario from the perspective of their own (Vesterinen *et al.*, 2019). Process steps that are unclear, unknown to agency representatives, or lack consensus among participants are flagged as a discrepancy (Vesterinen *et al.*, 2019).

Thereafter, participants are reassigned into multisectoral groups to develop a regional comprehensive map that incorporates the agency-specific maps and allows for the analysis of the multisectoral system. Areas of discrepancy are marked as 'control points' with the view of streamlining collaborations and communications at these points to strengthen the whole system (Vesterinen *et al.*, 2019). In order to increase its applicability and effectiveness, a 'train the trainer' model incorporates participatory leadership methods and facilitates training blended into the OH-SMART process (Vesterinen *et al.*, 2019). This iterative process that allows participants to learn as they do has contributed towards acquisition of key leadership skills such as improved self-awareness, enhanced negotiation and facilitation skills, practical approaches of implementing a systems thinking approach to OH complexities.

OH-SMART has been successfully implemented in over 37 workshops in 18 countries (Errecaborde *et al.*, 2017; Machalaba *et al.*, 2018; Pelican *et al.*, 2019; Vesterinen *et al.*, 2019). Areas of application have so far included national, sub-national and community-level action planning for zoonotic disease management, antimicrobial resistance, emergency preparedness and response, and OH workforce. The toolkit has been used both for preparedness and for after-action response evaluation, and 'just-in-time' OH events to rapidly improve multisectoral system function (Machalaba *et al.*, 2018; Pelican *et al.*, 2019; Vesterinen *et al.*, 2019). The proactive analysis to encourage preparedness has been the most popular approach in helping build surveillance, investigation, and response plans, and improving stakeholder understanding of the existing OH systems.

An example of this work was the National OH Workforce Planning done during the USAID OHW project by the OHCEA network in seven out of the eight OHCEA countries between 2017 and 2018. OHCEA is an international network of 24 higher education institutions located in 17 universities in eight countries in Africa. In February of 2017, 42 members of government and academic institutions from human and animal health were trained as facilitators from eight countries in Africa. In seven countries (Uganda, Kenya, Ethiopia, Democratic Republic of Congo, Senegal, Cameroon and Tanzania) the network supported these facilitators to implement workforce planning using the OH-SMART tool. This tool provided a framework to help visualize and analyse the individual and institutional workforce factors needed to facilitate multisectoral work. First, consultants synthesized and analysed existing known sector-specific needs and gaps through a systematic review of research and policy documents related to zoonotic disease control and workforce capacity from across the ministries of health, agriculture/livestock and wildlife/environment. These needs were consolidated across these sectors and cross-cutting themes and gaps identified and summarized into a synthesis report. These synthesized themes were then incorporated into multisectoral OH-SMART workshops to determine the individual and institutional multisectoral needs and gaps and develop action plans to address the gaps. The results were then validated by government ministries and policy makers. The OH-SMART tool was critical in mapping multisectoral responses to disease outbreaks, highlighting the key sector-specific, institutional and cross-sectoral gaps between sectors as potential areas for increased collaboration with government ministries and stakeholders. The validation of these reports by the government ministries and policy makers promoted their uptake for government implementation and partnerships.

The use of OH-SMART with OHCEA is an example of the importance of university–government partnership, which, we believe, greatly enhanced this multisectoral workforce planning effort. As a result of the OH-SMART planning, government officials in the various countries pledged their support to training institutions through new legislation, new funding and a commitment to strategic workforce development in order to support needs-based training and education for the current and future workforce around infectious diseases.

Programme leadership training attributes

Lessons learned from the development of OH-SMART master facilitators as OH leaders and champions in their countries include five key observations and assessment results:

1. The multisectoral and multidisciplinary nature of OH-SMART has been central to the success seen in the USA and abroad. Not only do multiple sectors and disciplines take part in the workshops, but the programme also uses trained master facilitators drawn from both government and academic positions with areas of expertise in human, animal and environmental health. The diversity of perspectives and skills encourages cross-learning and active participation – each one recognizing their role in the success of the team. Such teams have a higher self-correcting capacity and thus adapt easily to address both internal and external challenges.

2. Facilitation during these workshops and within these multisectoral teams is critical. The role of an unbiased convener who is able to step out of their disciplinary roles and assume a neutral perspective facilitates harnessing the group's wisdom and guides it towards collaborative problem solving. This ability to provide a safe zone for expression of multiple views allows for better communication, increased group cohesion and improved team efficiency.

3. Good interpersonal dynamics in a team increases team efficiency. As part of the facilitator and leadership training, participants are taught about the importance of self-awareness and the awareness of other personality and cultural styles (both strengths and weaknesses). The most successful OH leaders emerging from this training and mentoring process are those who are able to use these skills and leadership attributes to improve interpersonal interactions and processes within the teams and in their day-to-day work and by so doing improve team and workforce functioning (Cooke *et al*., 2013).

4. The emphasis on adopting an 'as is' view of the system during the multi-stakeholder analysis of the OH system being reviewed quickly generates an understanding that no single person knows the entire system. With this realization, participants are able to transcend their usual sector-specific territorial responses and adopt a more open and collaborative approach that allows each participant to be viewed as a vital part of the problem-solving mechanism for the team. This increases group cohesion through cognitive interaction and coordination (reflected by the quality of communication within the team) resulting in the development of creative solutions due to the diversity of thoughts and strategy that is brought to fruition (Fiore *et al*., 2010a; Cooke *et al*., 2013).

5. Regardless of the geographical or institutional boundaries, the most successful master facilitators are those who have applied an entrepreneurial (bold and creative) approach to implementation of OH-SMART in addressing their OH challenges. Such trainees have been proactive, adaptive and independent, and extremely collaborative, often working as advocates or champions for the OH approach within their organization or jurisdiction. These successful facilitators take advantage of the flexible nature of the process to develop permeable teams (i.e. allowing team members to move easily and quickly across team boundaries) that are fluid and can easily incorporate new ideas and additional members as the need evolves or scale/focus of the challenge changes.

Case 5: OHCEA One Health Field Attachments/Placements

Across Africa, the USAID OHW project has partnered with the OHCEA university network to develop experiential learning programmes known as 'One Health Field Attachments'. These field-based training experiences deploy students to communities at high risk for complex challenges at the changing human–animal–environmental interface. Training and mentoring for these programmes is designed to foster and mentor diverse student teams – that encompass a mix of different disciplinary expertise – to work together to effectively address complex community health problems. In particular, they aim to help student team members learn expertise in several OH core competency areas including: (i) community engagement; (ii) communication; (iii) entrepreneurship; (iv) teamwork; (v) project management; (vi) government engagement; and (vii) leadership.

Design and structure of the programme

The One Health Field Attachment programmes use previously identified demonstration sites where students are 'attached' to live and work in teams. These sites are typically located in rural communities that face a number of OH challenges (such as human–wildlife conflict). While at the site, the student teams work closely with community partners to assess community strengths and concerns and then work as a team to develop specific, innovative interventions based upon the findings from the community needs assessment.

OHCEA's approach to training future OH leaders involves a curriculum that emphasizes team building, adaptability, systems thinking, and cultural appreciation and competence. The programme encourages multidisciplinary teams to work together to identify and design interventions for community needs. Putting together such diverse teams is not an easy process. In Kenya, for example, the activity leaders spend nearly a week orienting students before going into the field. During this time, students are encouraged to learn about the disciplinary background and knowledge of the others within the team, so that they know what types of expertise they bring to the table. When students are working in the field, this team ethic is repeatedly promoted through informal means by having students live together and engage in various team building exercises.

The programmes also seek to build OH leaders that can adapt to a variety of situations. For many students, this programme presents the first opportunity that they have to work alongside students of other disciplines. Immediately, they are asked to work outside of their comfort zone and to collaborate with others who may not share their views or may approach problems from a different perspective. Aside from instilling future leaders with adaptive qualities, the programmes themselves react to changing situations. For example, as the Rwandan faculty were preparing to send students to the field, the demonstration site was identified as an area with an outbreak of Rift Valley fever in 2018. Activity leaders turned this challenge into an opportunity by collaborating with government officials so that students could actively participate in outbreak-response activities.

The programme also places a large emphasis on promoting cultural competencies in students to make them effective leaders. This ability to appreciate and work among diverse cultural contexts extends both to the cultural differences that exist among the various students and to the cultural specificity of the communities in which they work. In Kenya, significant time is spent learning about different disciplines, backgrounds and purviews. Additionally, students learn about the Maasai communities and culture that serve as demonstration sites. From the start of the experience, the teams work in close proximity with community leaders and village chiefs to ensure that every aspect of the programme is respectful towards the community and its beliefs, and teams are ultimately more effective.

Programme leadership training attributes

The One Health Field Attachment programme has evolved and adapted since its inception. Originally, a community-engaged faculty working in Uganda began to create and document what a formal field attachment would look like with an OH component. Throughout the region, many universities have existing field attachment activities or close relationships with community learning sites. However, these programmes are usually clinical in nature and geared towards students from a single discipline. The first programme was designed and implemented by Makerere University in Uganda in 2014. It consisted of nursing, veterinary medicine and public health students who spent 6 weeks at a demonstration site in the western part of the country. This programme was originally intended as a one-time event but, due to its popularity, was replicated in Tanzania, and today is carried out by nearly every country in the OHCEA network. Network-led evaluation activities have included interviews with students, faculty and community members. Results indicate that not only did students benefit, but communities also see value in working with these dynamic multidisciplinary teams to meet their needs, and faculty members learn alongside the students in how best to implement OH action.

Analysis and Results from Five Case Studies

Based on the case studies presented, we compiled a list of competencies and skills highlighted for each programme. These were then grouped into five overarching competency domains that the case studies highlight as important for the success of their programmes: (i) fostering collaboration and trust; (ii) innovation and adaptability; (iii) systems-based problem solving; (iv) mobilizing support; and (v) model behaviour. Table 15.1 summarizes the sub-domains from the case studies grouped under each domain, listed in descending order from most represented in the case studies to least represented (number of case studies in parentheses).

Table 15.1. Competency domains highlighted in the One Health (OH) leadership case studies with grouped sub-domains listed in descending order, from those most represented in the case studies to those least represented. (The number of case studies represented are shown in parentheses.)

Fostering collaboration and trust	Innovation and adaptability	Systems-based problem solving	Mobilizing support	Model behaviour
Communication (5)	Entrepreneurship (4)	Systems thinking (4)	Negotiation (2)	Empathy (2)
Cultural competency (social and sectoral differences) (5)	Adaptability and resilience (4)	Problem solving (4)	Influencing and advocacy (2)	Self-awareness (2)
Teamwork/foster trust in team (4)	Brainstorming (3)	Planning (3)	Policy and risk communication (2)	Dedication (2)
Multisectoral/ multidisciplinary engagement and work (4)	Creative thinking (2)	Systems visualization and analysis (1)	Public and community outreach and engagement (2)	Discipline (1)
Fostering collaboration (3)	Responsiveness to emerging needs (2)	Qualitative analysis (1)	Diplomatic tools and approaches in mobilizing leadership (1)	Emotional intelligence (1)
Facilitation (2)	Comfort with unknown and new situations (2)	Critical thinking and decision making (1)	Government engagement (1)	Ethical programme implementation and human interactions (1)
Multisectoral partnership (2)	Independent thinking (2)	Project management (1)		Integrity (1)
Group dynamics and conflict resolution (2)	Open-mindedness (1)			Wisdom (1)
Active listening (1)	Innovative thinking and action (1)			Respectful behaviour (1)
Promoting harmony (1)	Flexibility (1)			Taking responsibility (1)
	Vision generation and promotion (1)			Supportive of others (1)

In addition to these highlighted competency domains and sub-domains, another common factor to the success of all the programmes highlighted is the emphasis on OH action over theory. The students and trainees become OH leaders through the experience of working in multidisciplinary teams and working with many sectors (government, private sector, academia, community, etc.) to implement their work (Berger-González *et al.*, Chapter 6, this volume). Finally, a number of the case studies focus on entrepreneurship and innovations that result in economically viable solutions in the field.

What Did We Learn?

In addition to the need for further development of OH as an approach, developing OH leaders is of the utmost importance to develop a 'multiplying' effect. The development of successful OH leaders is not well understood nor documented. In this chapter, we present five case studies supporting the development of OH leaders. These studies offer insights into potential generalizable lessons that include classroom and experiential training that promote the need for interdisciplinary engagement, multisectoral collaboration and cultural awareness.

The key leadership competency domains and sub-domains are highlighted in Table 15.1. This list of competencies is not exhaustive or complete and should not be 'considered as a repeating refrain that reinforces particular ways of thinking and behaving that ultimately limits the ability of organizations to engage with and embed more inclusive and collective forms of leadership' (Bolden and

Gosling, 2006, p. 147). To that end, although these presented competencies are based on a very small sample size, and reflect the biases of a small (though diverse) group of authors as to what they would consider successful OH leadership, they do help reinforce, validate and add to a growing literature and consensus on what training for OH leadership entails. In fact, the case studies provide an opportunity to highlight some of the high-level competency domains previously described and lay out more detail on what sub-domains and competencies might contribute to the development of OH leaders and champions.

Hueston *et al.* (2018) outlined four major competency domains on OH leadership: (i) teamwork; (ii) critical thinking; (iii) interpersonal skills; and (iv) key knowledge. Similarly, in Frankson *et al.*'s synthesis of three different versions of OH competency domains (Bellagio, Stone Mountain and USAID RESPOND), OH leadership was prominent in all three sets of domains and included the sub-competencies critical thinking, conflict resolution, vision and strategy (Frankson *et al.*, 2016). The few example competencies presented emphasized leaders as change makers and data-informed advocates (advocating for change, fostering a change environment, understanding individual and shared leadership models, and possessing an external awareness (social, political, legal and cultural)). Compared to these published leadership competency domains, the competency domains represented in the OH leadership case studies provide a similar emphasis on fostering multidisciplinary teams and evidence-based change management including the domains: fostering collaboration and trust, systems-based problem solving, and mobilizing support. However, possibly because our case studies heavily emphasize the adaptation of OH in a global context, including four that have primarily been implemented in lower and middle-income countries, these domains and competencies include a heavier emphasis than previously published on practical and economically viable solutions to meet local needs (innovation and adaptability) as well as on individual traits and characteristics of personal integrity (model behaviour). Of particular note, the importance of understanding and mobilizing team members and engaging OH challenges that cross cultural lines came out very strongly in these cases with sub-domains like cultural competency, empathy, community engagement, emotional intelligence and respectful behaviour infusing a number of the competency domains. Despite vision being a primary OH leadership sub-competency in the Frankson *et al.* (2016) competency synthesis, vision per se was not a major focus of these OH leadership programmes, possibly because this may be seen as more theoretical in these contexts.

Critical to the success of these OH leadership programmes, is that they focus on OH action rather than theory. The success lies in the students and trainees actually doing OH work in collaborative groups and teams and addressing real-world problems. This kind of commitment and cooperation with people from different sectors and social groups was often discussed across these programmes as the most challenging aspect of the training and yet was also considered the most impactful in terms of changing attitudes and building cooperative skills. In several of the cases, it was emphasized that cultural competency must emphasize both the differences in institutional and disciplinary culture represented by different sectors as well as the differences in social norms and values represented by different cultural classes and ethnic backgrounds. To lead a diverse team, it takes self-awareness, time commitment, skill and practice to support understanding and acceptance of these differences in order for the team members to work together effectively. Yet the process of working through these cultural and sectoral differences to gain a shared understanding of a complex problem and develop potential solutions emphasizes the interdependence within the group, enhances coordination or team cognition, and thus improves team effectiveness (Fiore *et al.*, 2010b). The case studies provide evidence for how team diversity initiates and stimulates collaborative problem solving and cooperative leadership, seen as a critical aspect of OH leadership.

Related to the emphasis on OH leadership being about practical work in the field, these programmes also present a strong case for focusing OH leadership training on practical, experiential fieldwork. The multidisciplinary nature of working in the field in OH groups allows trainees exposure to different ways of interacting and thus development of more flexible and adaptive team dynamics, supporting greater capacity to address complex team challenges. From a student perspective, deliberate structuring of programmes with an emphasis on field experiences and real-world problem solving promotes leadership training and community engagement (Berger-González *et al.*, Chapter 6, this volume).

These training opportunities, all based in universities, offer a strength-in-numbers approach to OH leadership training. University programmes, once established, can be extremely stable and sustainably build the capacity of generations of workers into the future. Universities are the primary training institutions in a country for health professionals needed on OH teams such as human health, animal health and environmental professionals and scientists. While not all students or trainees passing through university training programmes will become OH leaders, select students certainly will. Based on the training they receive, they can use the leadership training provided to inspire action in the next generation of OH workers to communicate effectively, think collaboratively and work cooperatively, resulting in a sustained, effective OH workforce, and an operational OH system in countries.

Conclusion

While many studies have evaluated OH competencies and leadership skills, one of the primary OH leadership competencies needed is working successfully across disciplines and cultures. Leaders must be able to adequately interact with numerous stakeholders, from government officials to community members. The cases presented here both support and expand our understanding of OH leadership through a lens of adapting OH training to a global context. The OH leader in this context fosters teams and uses systems-based problem solving. However, a greater emphasis is placed on cultural competency, personal integrity and effective and economically viable solutions to make OH operational in the field rather than more theoretical concepts like leadership vision. Ultimately, operationalizing OH in countries requires large-scale sustained experiential OH leadership training programmes. University-led field-based OH training programmes like the cases presented here provide a road map and strengthen long-term OH leadership into the future. Ultimately, incorporating these competencies into university training programmes will build and strengthen how global health emergencies and challenges are managed.

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16 The Practice of One Health: Lessons Learned

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Introduction

The phrase 'the practice of One Health' evokes a compelling image. But even those who contribute to and benefit from One Health practice are unlikely to share a single concept of what the term means. The word 'practice' in the health sector is often taken either as an individual or group of professionals who share their resources and skills to provide a service (such as in a veterinary practice) or as the use of professional knowledge and skills to improve health outcomes. Service, or the desire to help solve a problem, is a defining feature of health practice. Most broadly, one could say that One Health practice strives to identify health problems, along with the factors that cause them, somewhere in the nexus of human, animal and environmental health. It aims to develop strategies to address these problems and see these strategies implemented in ways that work. It involves collective efforts of a diversity of professionals, often acting with community partners, to identify and address cross-species and cross-sectoral health problems. A more precise definition of One Health practice is complicated due in part to the lack of a shared definition of One Health as well as to the wide diversity of problems, approaches and personnel that operate under the banner of One Health. In this book, we define One Health as added value of a closer cooperation between human and animal health that could not be achieved if the two disciplines worked in separation (Zinsstag *et al.*, Chapter 2, this volume). This chapter combines the lessons described in chapters throughout this book with my own personal experience to propose ten characteristic components of One Health practice, shown in Box 16.1.

Component 1: It Has a Shared Vision of the Task at Hand

A shared vision of the problem to be solved and the role of the team in addressing the problem are at the core of successful One Health practice. Not only must there be a shared vision, but the task at hand must also provoke passion and enthusiasm among the collaborators (Anholt *et al.*, 2012). A successful One Health practice leader must be skilled in finding a clear direction that resonates across all those involved in the problem at hand, striving to achieve an incremental benefit from a closer cooperation (Zinsstag *et al.*, Chapter 2, this volume). White *et al.* (Chapter 3, this volume) emphasize the criticality of well-articulated goals and objectives in framing a One Health problem in order to establish the boundaries for One Health action and investigation. Given that there will be a variety of interest in any human–animal–environment system, having a shared set of values that drive the direction of an intersectoral group is important for success (Nancorrow *et al.*, 2013). Tschopp and Yahyaoui (Chapter 22, this volume) use bovine tuberculosis in Africa to illustrate how goals and priorities may differ for conservation versus agricultural versus public health sectors of One Health and how a shared vision is needed to coordinate efforts. As mentioned by Stephen *et al.* (Chapter 17, this volume), One Health practice requires visionary leadership to align diverse professional community with

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Box 16.1. Ten characteristic components of One Health practice.

- It has a shared vision of the task at hand.
- It seeks practical, timely solutions.
- Attention to relationships is essential.
- It is a transdisciplinary team activity engaging academic and non-academic stakeholders.
- Animals are a defining feature.
- It is based on an expanding scope of science.
- It lies along a continuum of research and practice.
- It is embedded in the local level.
- It needs critical evaluation.
- It needs to address the health of the environment.

partners who need to collaborate. Finding the shared vision for practice may be forthcoming for a research project (where agreement on the most appropriate testable hypotheses may be more readily achieved) or in clinical practice (as exemplified by Hediger and Beetz in Chapter 26, this volume, on mental health) but can be more challenging for socio-ecological systems-based One Health problems (e.g. waste management and food security, as discussed by Nguyen-Viet *et al.*, in Chapter 13, this volume and Gordon *et al.*, in Chapter 25, this volume, respectively).

Component 2: It Seeks Practical, Timely Solutions

While there are a variety of definitions, in this book we emphasize good One Health practice as added value of a closer cooperation. Consequently, we propose that One Health practice is 'good' when it produces outputs that cannot be achieved by working in isolation and supports the realization of desired impacts on health outcomes in a timely fashion. For example, integrated West Nile virus surveillance in mosquitos, wild birds, horses and humans in Italy was able to timely prevent the use of contaminated blood for humans because of the earlier detection in animals (Paternoster *et al.*, 2017). Examples provided by Oura *et al.* (Chapter 28, this volume) highlight how a pragmatic and problem-solving focus was important for the success of some One Health organizations. One Health practice does not necessarily have the goal of evaluating a problem in one situation in order to identify theories of causation or establish generalizable rules of risk management; that instead falls into the realm of One Health research. Component 6 (below) deals with the interdependence of practice and research, but it is important to note this distinction to help set realistic goals for research versus practice. The task of researching causal relationships or evaluating the efficacy of interventions are tasks which, on their own, can be overwhelming due to the complex interactions of human, animal and environmental attributes of a problem. Adding the challenges of mobilizing that knowledge into action across a diverse set of One Health stakeholders adds an additional level of complication and complexity. One Health practice builds on research results by mobilizing information and capacities to inspire effective, ethical and sustainable actions in 'real-world' settings to address complex problems important to people, animals and/or ecosystems with highest leverage and best cost-effectiveness (Zinsstag *et al.*, Chapter 31, this volume).

An action orientation that strives to inspire change under real-world conditions permeates many examples in this book. Chapters on antimicrobial resistance (Szelecsenyi *et al.*, Chapter 18) and control of rabies (Léchenne *et al.*, Chapter 19), brucellosis (Schelling *et al.*, Chapter 20) and tuberculosis (Tschopp and Yahyaoui, Chapter 22) exemplify One Health practice targeting infectious disease control at the source. Chapters on climate change (Stephen *et al.*, Chapter 17), non-communicable diseases (Turner and Hediger, Chapter 23; Hediger and Beetz, Chapter 26), disaster management (Gallagher *et al.*, Chapter 24), food security (Gordon *et al.*, Chapter 25) and the spiritual dimension (Fries and Tschanz Cooke, Chapter 27) show how One Health in practice can help reduce harm from non-infectious persistent problems through using multi- or interdisciplinary approaches.

Component 3: Attention to Relationships is Essential

An explicit dedication to relationships is essential to One Health practice in two senses. First, the source of and solutions to One Health problems are found in the interactions originating from animal, human and environmental relationships. Social and ecological relationships are essential determinants of One Health problems because the lives and existence of people, animals and environments are interconnected and dependent on each other. One Health practice is, in part, a response to the call for systems thinking in health sciences that arose from frustration that evidence derived from highly controlled research that constrained the numbers and variety of variables and relationships being studied failed to inspire action which improved health outcomes (Häsler *et al*., Chapter 10, this volume). Past failure of unidisciplinary programmes to inspire actions against emerging infectious diseases was, for example, a driver of adopting multisectoral, systems-based methods like One Health (Burns and Stephen, 2015). One Health hopes to identify critical relationships in the social and physical spaces shared by people and animals in order to inspire more timely, effective and efficient health protection actions.

In the second sense, One Health cannot happen without fostering and supporting relations across the diversity of people, disciplines and communities involved in the genesis of or solution to One Health problems. Transdisciplinary participatory approaches co-producing transformational knowledge between academic and non-academic actors is at the heart of One Health (Berger-González *et al*., Chapter 6, this volume). Scientists, communities and authorities interact and bridge One Health research and practice to identify practical solutions. One Health practice takes place in a new shared space, where single agencies or individuals no longer act as independent entities (Stephen and Stemshorn, 2016). Ideas, information, resources and people need to be connected to tackle One Health challenges. This book provides many examples where improved communication, consultation and partnerships were needed to deploy cross-disciplinary capacities to solve shared problems. For example, Hediger and Beetz (Chapter 26, this volume) introduce the idea of better integration of animal welfare and human mental health to create win-win animal-assisted therapies that benefit people and animals. Connecting people across the entire food chain from producers to consumers is critical to deal with food security issues, as described by Gordon *et al.* (Chapter 25, this volume).

Parkes *et al.* (2005) highlighted the need to link knowledge across perspectives and among different knowledge users for effective responses to emerging infectious diseases. One Health practice aims to connect disciplines, expertise, technology and the people who can act to protect health. The connections and efficiencies created by collaborative solutions build the necessary trust to turn knowledge into solutions. Personal relationships built on trust and respect are needed to best assemble the disciplinary strength of the professions working in a One Health manner (Anholt *et al*., 2012) and are critical to knowledge creation and knowledge transfer in any collaborative setting. Personal relationships are one of the three critical components of successful One Health partnerships, along with a task that incites enthusiasm and competent individuals (Anholt *et al*., 2012). Cross-disciplinary collaborations and trusted relationships help One Health practitioners to see the possible unexpected outcomes of their decisions and actions more clearly.

Component 4: One Health Practice is a Team Activity

It is unreasonable to expect any one person or single discipline to possess all the essential skills, knowledge and attitudes needed for effective One Health practice. The importance of the team approach is found throughout the examples in this book. Transdisciplinary approaches are described as a foundational approach to One Health by Berger-González *et al.* (Chapter 6, this volume). Gallagher *et al.* (Chapter 24, this volume) make a clear case for a team approach in acute health problems, in this case, response to disasters. Other authors, like Léchenne *et al.* (Chapter 19, this volume) on rabies control and Schelling *et al.* (Chapter 20, this volume) on brucellosis control, show the critical interdependency of human and animal health sectors and evidence for an added value of a coordinated team-based approach. Turner and Hediger (Chapter 23, this volume) present a clear case for good communication, shared protocols and coordinated planning when developing animal-assisted therapies in the clinical management of non-communicable diseases in people. Skills in negotiating and translating priorities, perceptions and concerns across diverse sets of collaborators and stakeholders were critical to the success of some One Health organizations described by Oura *et al.* (Chapter 28, this volume). The variable and often hard-to-measure factors that characterize the complex interactions of people, animals and places can be disincentives for researchers and practitioners to adopt an interdisciplinary team approach. This is indeed the challenge that One Health in practice routinely confronts.

One Health practitioners must actively work to span the gulf between disciplines, responsibilities, species, evidence and places. This is best achieved when the team is assembled with people who are competent in their own discipline and are also predisposed to collaboration (Anholt *et al*., 2012). The challenge of combating antimicrobial resistance as described by Szelecsenyi *et al*. (Chapter 18, this volume) is an exemplar of the need for a broad, systemic cross-sectoral, team approach. One Health practitioners use techniques, knowledge and capacities to bridge single-purpose organizations that deal with only one aspect of a problem towards a more integrated team-based approach in science and government. Effective cross-sectoral teams promote a flexible juxtaposition of different disciplines, resources, knowledge and competencies working in a coordinated fashion towards a common goal. The ideal One Health team shares power and decision-making tasks and exchanges knowledge, skills and expertise that transcend traditional discipline boundaries (Stephen and Stemshorn, 2016). Team members are exposed to new information or ideas that would not come from their discipline alone when they avail themselves of what other One Health team members bring to the collaboration. This sharing of knowledge and information increases the chance of finding solutions to complex problems.

Collaboration does not happen automatically. It requires competence, confidence and commitment on the part of all parties (Nancarrow *et al*., 2013). Effective teams need to be skilled in group processes and team development as part of their practice (Stephen and Stemshorn, 2016). As Berger-González *et al*. (Chapter 6, this volume) illustrate, interdisciplinary team partnerships require time to develop, solidify and become fully functional and effective (Stephen and Daibes, 2010). Effective One Health practice must invest time and effort in fostering and sustaining relationships between people and organizations to build effective teams.

Component 5: Animals are a Defining Feature

One Health can in no way claim it is the only form of health research and practice that emphasizes interdisciplinary approaches that cross human systems with other social and ecological systems. The socio-ecological model of health sees health as a series of interconnected, co-dependent and interacting factors; in other words, as a system (Diez Roux, 2011). The socio-ecological model informs or underpins population health, health promotion, ecohealth and global health. But, as this book shows, animals are central to One Health issues and animal health professionals are the predominant (although far from exclusive) advocates and practitioners of One Health. Few, if any, One Health projects fail to have some concern with how animals and people interact to affect health outcomes. To be exceptionally clear, I am not suggesting any conceptual ownership of One Health by animal health professionals nor minimizing the essential contributions of professions and partners outside of animal health professions: these are essential. I am simply proposing that an overview of this book, a scan of the literature and attendance at One Health conferences will show that One Health cases largely involve animal–human interactions. It is unfortunate that inclusion of other attributes of ecosystem or environmental determinants of health seem not to be an essential or a consistent feature of One Health. But without animals in the picture, it would be hard to claim something is One Health based on publications and practices to date.

This inclusion of animals in a health problem is not, however, a defining feature exclusive to One Health. Where animals are only seen as the source or signal of a public health threat, it is reasonable to suggest we are describing veterinary public health. When animals are studied as part of the ecosystem of a pathogen or parasite, we might reasonably describe a project as infectious disease ecology. It might still be hard to distinguish One Health from veterinary public health, environmental health, disease ecology, or other fields even after we consider all ten components proposed in this chapter. I am not sure it is even necessary to make such a distinction. One Health has refocused us on the simple fact that the health of animals, people and ecosystems are interdependent. Rather than worry about which field covers which problem territory, this book hopes to inspire continual attention to health as a product of the relationship with the world around us in order for us to 'get ahead of the curve' and find ways to promote and protect health of multiple species at the same time.

Component 6: One Health Practice is Based in Science, and the Scope of Relevant Sciences is Expanding

One Health practice and research are interdependent in part, due to the desire to undertake evidence-based practice. This book presents evidence of an added value of a closer cooperation between human and animal health and related disciplines (Chapter 31, this volume). The number of scientific papers aligning themselves with One Health has exploded in recent years, resulting in many new and innovative insights into the causes and effects of diseases or health threats.

One Health practitioners increasingly see the need to use concepts of evidence-based practice that extend beyond rigid biomedical science-based concepts to also include other forms of evidence, like traditional knowledge, social and political sciences, and systems science to better understand complex situations, which can result from transdisciplinary participatory approaches (Chapter 6, this volume). Policy research and human dimensions investigations have near equal footing with laboratory investigations and research on pathogenesis in the One Health world. In Chapter 10 (this volume) on economics Häsler *et al.* summarize financial benefits for One Health, and in Chapter 27 (this volume) on spirituality Fries and Tschanz Cooke emphasize that, for most people, a transcendent dimension to health is important. Readers will discover a breadth of research types scattered through the diverse chapters in this book. One Health practitioners need to think broadly and inclusively when considering what is meant by evidence in evidence-informed decision making.

Component 7: One Health Lies along a Continuum of Practice

Is it One Health? Is it ecohealth? Is it conservation medicine? There is growing discussion and debate around what is within One Health's scope of practice. The idea of a scope of practice describes the range of responsibility and issue within which a form of practice can legitimately and responsibly operate. An overview of the topics covered in this book suggests that the scope of One Health is big, broad and growing. One Health's scope of practice was much easier to define when the term first emerged. It focused on animals as sources and signals of infectious agents capable of causing outbreaks and pandemics of human infection. As the value of looking at health outcomes as results of interdependencies of human, animal and environmental health has grown in popularity and impact, so too have One Health areas of interest. One Health remains firmly rooted in understanding and managing emerging infectious disease threats but now endemic diseases of people and livestock, non-communicable diseases, pollutants, poverty reduction, food security, waste management, sustainable development and more are within its scope of practice. This evolution has begun to blur the lines between other multisectoral, socio-ecologic, systems-based, collaborative approaches such as ecohealth, planetary health and health promotion (Mallee, 2017).

Some people suggest this growth and blurring of the scope of practice suggests the need to bring One Health together with other forms of collaborative inquiry like ecohealth (Zinsstag, 2012). Others suggest there are important differences in the targets, methods and perspectives of approaches like One Health, ecohealth and planetary health (Lerner and Berg, 2017). Applying different perspectives to the same problem may accelerate innovation and launch multiple conclusions at different targets, an approach often needed to address complex health issues. Much intellectual effort can be allocated to defining and defending a field. Such effort can help refine and intensify the methodological development of a field and focus effort on to a particular aspect of a given problem. But, as we can see from many of the examples in this book, it does not really matter what we call it as long as people are coming together to rigorously and justly apply their skills and knowledge together to tackle some of society's most challenging and perplexing health issues. I, for one, am glad to see the expanding scope of practice of One Health reflected in this book, as it indicates more people and resources are dedicated to find ways to concurrently protect the health of people, animals and our shared environments through the incremental benefit of a closer cooperation of different disciplines and sectors.

Component 8: There Must Be a Connection to the Local Level

International and national commitments to One Health can help empower local One Health practice by providing an enabling environment, but actions and decisions made at the local level determine whether we can successfully effect changes in public health, conservation, food security and other One Health outcomes. One Health is inherently collaborative and cooperative, engaging scientists with communities, authorities and other actors (Berger-González *et al.*, Chapter 6, this volume) to pay attention to people whose knowledge and perspectives are required in order to turn research and surveillance into action. Interventions need to be tailored to the local conditions.

> By connecting ideas, evidence and innovation from one sector to another and linking with communities and governments with the ability to act, One Health reduces the likelihood of unintended effects and increases the likelihood of more acceptable and effective actions.
>
> (Oura *et al.*, 2017, p. 90)

This is not unique to One Health. Closing the gap between knowing and doing in all fields requires processes to link knowledge creators and knowledge users. The Knowledge to Action Framework recognizes that a critical first step in knowledge mobilization is cultivating trust and relationships between knowledge creators and knowledge users to establish a common understanding of needs (Graham *et al.*, 2006).

Component 9: One Health Practice Needs Critical Evaluation

The benefits of One Health have historically been attributed to increasing public health efficiency and cost-effectiveness through a better understanding of disease risk through shared control and detection efforts (Baum *et al.*, 2017). With its increasing popularity, pressure has been put on One Health to prove its benefits. There is a slow but growing movement to eliminate this characteristic component of One Health but, to date, One Health has been subject to little critical evaluation, especially with respect to its ability to result in more effective solutions. Metrics like journal impact factor and citation rates give a shallow and incomplete picture of impact (Jarwal *et al.*, 2009). Some attention has been placed on the economic efficiency of One Health, like cost–benefit or cost–utility ratios as well as on disease frequency or disease burden measurements (Falzon *et al.*, 2018; and as discussed by Häsler *et al.*, Chapter 10, this volume). But like many interdisciplinary health endeavours, there is still scant evidence that allows us to provide evidence-based recommendations for when a One Health approach results in better health outcomes than alternative approaches. There is even less evaluation of the implications of health improvements in one part of the One Health triad on the other two components. Most attention has been focused on how One Health can improve human health or human social outcomes. One of the major challenges to evaluating an approach predicated on integrating a diversity of disciplines and perspectives is that there are no universal criteria to judge suitability or quality of a practice. One Health relies on collaborating disciplines with their own underlying theories rather than being its own discipline with its own theoretical foundations. This results in different understandings and applications of One Health. Increasing attention is being placed on creating One Health theory (Zinsstag *et al.*, Chapter 2, this volume) and methods (Schelling and Hattendorf, Chapter 8, this volume), without which it is challenging to generate enough evidence that is comparable and transferable between studies and settings to allow for generalizable conclusions on One Health's effectiveness or efficacy.

There is a growing recognition of the need to evaluate One Health, in part to support the dedication to evidence-based practice. The Network for Evaluation of One Health (NEOH), for example, promotes quantitative One Health evaluations. NEOH provides guidance and practical protocols to help plan and implement evaluations in order to produce meaningful information about the value of One Health (Rüegg *et al.*, 2018). Lessons taken from Häsler *et al.* (Chapter 10, this volume) on One Health economics, and Zinsstag *et al.* (Chapter 31, this volume) on measuring added value from One Health, can serve as a foundation for those wishing to add to the evidence base to assess how and when a One Health approach is the best choice.

Component 10: One Health Needs a Stronger Environmental Orientation

Although wildlife and the environment are often seen as sources of hazards to people in One Health research and practice, they are rarely seen as part of the solution (Barrett and Bouley, 2015; Sleeman *et al.*, 2019). Even the common allocation of wildlife to the environmental pillar rather than the animal pillar of One Health shows a perspective focused on domestic animals and people as the recipients of care. One Health has paid relatively little attention to issues that threaten all forms of life on the planet like climate change, the extinction crisis and the loss of viable habitat (Stephen and Karesh, 2014). One Health is missing opportunities to concurrently optimize outcomes for human, animal and environmental health. White *et al*. (Chapter 3, this volume) make the case that a shift from disease prevention to health promotion to more fully integrate solutions that concurrently protect the health of humans, animals and ecosystems will facilitate a more seamless inclusion of ecological health and environmental conservation into One Health practice. A conceptual evolution of One Health to health in social-ecological systems has been proposed by some but its methodological validation is still in the early stages (Zinsstag *et al*., Chapter 2, this volume). The vision for a One Health approach to climate change described by Stephen *et al*. (Chapter 17, this volume) serves as a good reminder that approaching the threats to people, animals and ecosystems separately will be an inefficient, and likely ineffective, way for society to adapt to and cope with climate change.

Summary

These ten One Health practice components are entirely opinion based. In fact, there are ten simply because people like lists of ten (perhaps because people have ten fingers). These components are presented here in part as a reminder of some critical competencies, processes and perspectives needed to work across species and sectors as well as a reminder that work still needs to be done to fully realize the ideal of One Health in practice. They also serve to remind the One Health community to not get into battles over definitions and scopes of practice but rather to encourage contemplation on the methods and theories (see for example Zinsstag *et al*., Chapter 2, this volume; Schelling and Hattendorf, Chapter 8, this volume; and Zinsstag *et al*., Chapter 31, this volume) needed to promote and improve more effective application of the knowledge we generate as an inter- and multidisciplinary community to reduce harm from challenging health issues at the human, animal, environment nexus.

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17 Climate Change: the Ultimate One Health Challenge

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Overview

The negative health impacts of climate change are all around us, transcending species and geographical boundaries. Worldwide, people, animals and ecosystems are experiencing increased heat, extreme weather events, declining air quality, expanded ranges of parasites and pathogens and issues related to food and water safety and security. The health impacts of these environmental changes vary from acute to chronic and mild to severe, but collectively result in substantial physical, mental and economic stress. Human health-care providers have begun to advocate for climate mitigation and adaptation; however, there is a need for other health professionals to join in, and complement, these efforts. The pathogenesis and epidemiology of climate-associated disease in animals are like those in humans, providing opportunities for an intersectoral approach to understanding and adapting to climate change. Animals, particularly wildlife and those housed outdoors can be sentinels of human health threats, providing information on the importance of the local environment in climate change adaptation. This chapter provides an overview of the health impacts of climate change and the shared benefits of diverse collaborations to adapt to this important health threat.

Introduction

A growing number of countries and cities have declared climate emergencies as the anticipated consequences of climate change are occurring faster than expected (Mascarelli, 2008). Climate change refers to variations in the state of the Earth's climate that persist over a long time period. These changes may be a result of human activity (anthropogenic) or natural factors. Since the 1950s, however, climate change has been overwhelmingly driven by human activities, such as alteration of the atmospheric composition and land use (IPCC, 2013). The Intergovernmental Panel on Climate Change (IPCC) is the global scientific body of the United Nations that reviews and assesses climate science. In 2018, the IPCC published a special report on the impacts of global warming of 1.5°C above pre-industrial levels, which emphasizes the necessity of limiting global warming to 1.5°C in order to reduce risk to human health, biodiversity, fisheries, food security, water supply and ecosystems (IPCC, 2018). The impacts of climate change on human health are irrefutable and increasing. The World Health Organization has labelled climate change as the greatest threat to global health in the 21st century (WHO, n.d.). Even under the most optimistic scenarios, climate change will also impact the health of wild and domestic animals. While previously framed as an environmental problem, there is critical need to align the priorities of human, animal and environmental health professionals to address this threat. Despite being the quintessential One Health issue, relatively little has been said or done to apply One Health teams, thinking and resources to climate change adaptation and mitigation (Zinsstag *et al.*, 2018).

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Climate change will impact human, animal and environmental health by both amplifying existing health problems and creating unanticipated threats (Stephen *et al.*, 2019). Figure 17.1 depicts some pathways between climate change and health. For amplified problems, climate change adaptation is essentially a matter of ensuring accessible health services that can be deployed and/or enhanced in response to locally changing epidemiological situations. For example, tick-borne diseases are increasing across North America and climate change is one contributing factor. Reported cases of Lyme disease dramatically increased in Canada from 144 cases in 2009 to 2025 cases in 2017 (Government of Canada, 2018). The Government of Canada responded by publishing a federal framework on Lyme disease in 2017 that called for collective action on surveillance, education and awareness, and development of guidelines and best practices (Government of Canada, 2017). The impacts of the northward range expansion of the tick vector are not restricted to humans. *Borrelia burgdorferi* can infect a variety of animal species with outcomes ranging from asymptomatic infection to severe illness, and Lyme disease is a growing concern for pet owners and veterinarians in Canada (Bouchard *et al.*, 2015). Canine seroprevalence correlates strongly with human risk and, in some circumstances, high canine seroprevalence appears to anticipate increasing rates of human infection (Mead *et al.*, 2011), suggesting that coordinated surveillance activities to this known threat could increase preparedness across species.

Addressing unanticipated threats requires that capacity is prepared for and can adapt to surprising events. Although long-term climate change can have serious consequences, extreme or surprising events cause the most damage to human health (Streets and Glantz, 2000). Shifting climate regimes will alter biotic communities in surprising ways,

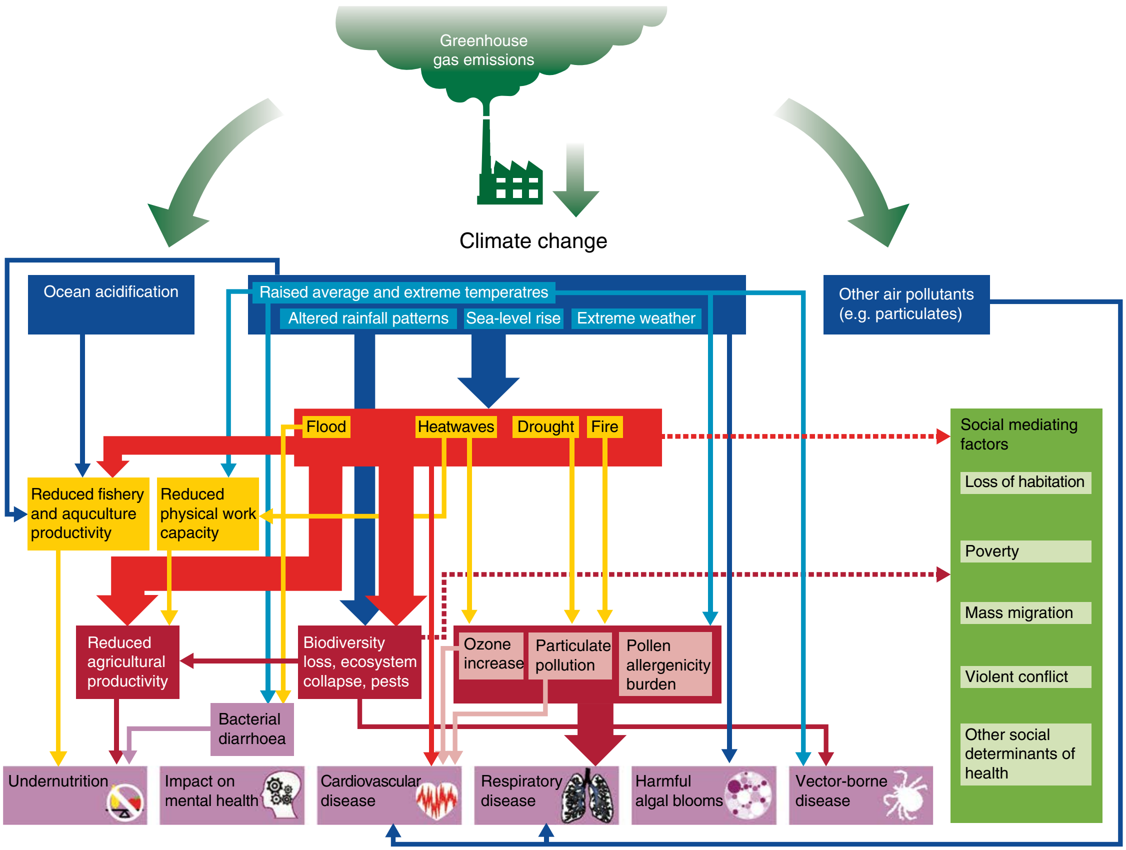

Fig. 17.1. Some pathways between climate change and health. From Watts *et al.*, 2018, reprinted with permission.

leading to new and unanticipated opportunities for pathogens, parasites and pollutants to move between species (Williams and Jackson, 2007). Interactions of management factors, climate change effects and natural histories are also resulting in unanticipated impacts on conservation and food security, as exemplified by changes in phenology affecting fish migration and reproduction (Peer and Miller, 2014). Preparing for surprises will require expanding partnerships and perspectives by linking knowledge and intelligence bases, such as meteorological monitoring, entomological data, water quality records, air quality measures, remote sensing information, geology, population density, and many other information sources with health information, across species. One Health stewardship in the face of climate change means promoting a continuum of care that will prevent anticipated impacts, resist unanticipated impacts and ensure recovery without persistent and irreversible harms. It means strengthening health and food production systems, protecting biodiversity and addressing the needs of the most vulnerable in the current and future generations.

An Overview of Climate Change and Health

Medical professionals are increasingly aware of the negative impacts of climate change on human health, however, more education and training is needed, starting with medical school curricula (Vogel, 2019). Climate change impacts people around the globe through extreme heat, air pollution, increased allergens, reduced food and water quality and quantity, population displacement and changes in vector ecology. The resulting direct and indirect health impacts of climate change are well described, including heat-related illness and death, vector-borne diseases, food insecurity and malnutrition, injuries, gastrointestinal illness, worsening mental health, and respiratory and cardiovascular disease (CDC, 2019). Some of the more vulnerable groups include children, older adults, pregnant women, persons with chronic medical conditions, and those with lower socio-economic status (Global Change Research Program, 2016). Climate change impacts the health sector and utilization of health services. For example, poor air quality as a result of increased number and frequency of wildfires can result in more visits to a healthcare provider (Green Health Care, n.d.). One study estimated that the actual healthcare cost associated with six climate-related events in the USA between 2000 and 2009 was US$740 million (Knowlton *et al.*, 2011).

Animal health impacts of climate change vary widely by species, location and management. The effects of climate change on animals have been seen, or are assumed, to generally parallel those of humans, however, the literature on climate change impacts on animals to date is sparse in comparison to what has been produced for people. Production, health, welfare and economic impacts of heat stress have been well characterized for a variety of animal agriculture systems (Nienaber *et al.*, 1999; West, 2003; Polsky and von Keyserlingk, 2017) and are anticipated to increase with climate change (Lacetera, 2018; Summer *et al.*, 2018; Gunn *et al.*, 2019). As with people, climate-induced changes in vectors will change the geographic and temporal range of some infectious diseases. For example, the costly establishment and spread of bluetongue virus in Europe has been attributed to climate change (Purse *et al.*, 2005; Wilson and Mellor, 2008). Climate models predict still increasing disease risk in northern latitudes, highlighting the need for appropriate animal surveillance and regulation (Jones *et al.*, 2019). Climate change also has the potential to alter host–parasite relationships (Kutz *et al.*, 2005), which in turn can impact morbidity and mortality. The pathogenesis of lung disease secondary to smoke and air pollution is relatively consistent across species; a long-term study on dairy cattle in Belgium, for example, found a significant association between ambient air pollution and cattle mortality (Cox *et al.*, 2015, 2016). Wildfire smoke is known to harm both domestic and wild animals (Marsh, 2007; Erb *et al.*, 2018). The impact of climate change on plant diseases and crop production (and the resulting impacts on food security) will be similar in domestic animals as it is in humans (Chakraborty and Newton, 2011). For animals dependent on surface water, climate change-induced drought, infectious disease and algal blooms have been associated with animal mortality events (Oberholster *et al.*, 2009; Bett *et al.*, 2017). Different animal species and populations will have different capacities to cope with climate change. The focus of the general discourse on climate change and animal health is too often limited to identifying and managing emerging risks, rather than building coping capacity in advance of climate change harms (Stephen *et al.*, 2019). Coping capacity in domestic species is closely related to the ability of the animal managers to offset changes through management. In the case of wildlife or animals in low resource areas, coping capacity will be limited by the state and availability of critical ecosystem services and/or financial resources. The drivers of climate change maladaptation will not simply be mediated by changing hazard–climate interactions but will be modified by other global trends such as landscape change, wildlife exploitation, globalization, agricultural intensification and urbanization.

Climate change is likely to modify the already complex relationship between human and animal health. The nature of food production systems under climate change conditions, and how that might be influenced by alternative decisions, is uncertain. People in developing countries whose subsistence livelihood depends mainly upon livestock production are most acutely affected by this uncertainty. The 2019 General Session of the World Organisation for Animal Health (OIE), for example, noted that climate change impacts on animal infectious diseases and veterinary services could threaten sustainable development (OIE, 2019). Livestock production is seen both as an important contributor to human community resilience through poverty reduction and food provision (Randolph *et al*., 2007) at the same time as being seen as a climate change contributor responsible for approximately 14.5% of the world's greenhouse gas emissions (Gerber *et al*., 2013). Animal health impacts will influence people through multiple pathways. These can be relatively direct such as the economic consequences of heat stress in animal production systems (St-Pierre *et al*., 2003) or the modification of the food products themselves, such as altering the organic and inorganic components in milk (Gunn *et al*., 2019). Climate change will affect the nature and location of livestock systems by altering livestock determinants of health, which in turn will affect their availability and sustainability for poverty reduction and food security (Thornton *et al*., 2008). Uncertainty about the best management options for longer-term adaptation in the livestock sector is limited by uncertainty in the impacts of climate change, and limited information on the best response strategies for profitable farming (Henry *et al*., 2012). The impacts on food accessibility and quality attributed to climate harms to livestock production coupled with unknown effects on productivity and diseases of animals will require adaptive and innovative approaches (see also Gordon *et al*., Chapter 25, this volume).

The current and projected impact of climate change on aquatic-based food systems is also substantial. Worldwide, marine productivity declines are predicted to decrease the fishery yield by more than 20% globally and 60% for the North Atlantic (Moore *et al*., 2018). Other food system pathways are more complex, such as how ocean acidification from climate change is impacting coral reefs, which in turn impacts nursery areas for wild fish that form the basis for coastal fisheries which are critical for ecosystem integrity and conservation as well as food security and income in poor smallholder coastal communities in tropical regions (Allison *et al*., 2009). There is a widespread lack of targeted analyses of the fisheries and aquaculture sectors' vulnerabilities to climate change and associated risks, as well as the opportunities and responses available (Barange *et al*., 2018). Climate change is also projected to be a significant contributor to local extinction of marine species in the sub-polar regions, the tropics and semi-enclosed seas. Together with new species invasions due to climate or human-induced changes in species distribution, the resulting ecological disturbances will disrupt ecosystem services needed by people and animals (Cheung *et al*., 2009).

No aspect of animal, human and ecosystem health will be untouched by climate change. New research on the relationship of climate and health has its own merits but without the capacity to effectively get this knowledge to the people who can act to make the necessary changes, little will come of it. Failing to prioritize research, policies and actions to address the shared threat of climate change for people, animals and ecosystems will have significant implications for all aspects of One Health, ranging from disease prevention to food security to community resilience.

How Can a One Health Approach Be a Useful Part of a Climate Change Strategy?

There are three driving reasons to promote intersectoral collaboration in the battle against climate change. First, the unprecedented rate of social and ecological change accompanying climate change will make it inefficient to tackle one problem at a time, using knowledge, resources and expertise in isolation. The second reason is to avoid unanticipated effects. Working together will reduce the likelihood that efforts to reduce risk or promote resilience in one species will unintentionally reduce the capacity for health in other species and future generations to adapt to a new climate regime. Thirdly, common messaging across species and sectors may more effectively influence social norms and perspectives that influence people's perceived empowerment to act.

Incomplete knowledge of health risks and limited awareness of best health protection practices are barriers to climate change adaptation (Berry *et al*., 2008). Effective climate change preparedness not only must have the best current intelligence but also requires an indication of what the future may bring (Stephen and Duncan, 2017). Adoption of a One Health approach to climate change mitigation and adaptation could create knowledge sharing efficiencies required to address the looming health challenges (FAO, 2009). The Canadian Public Health Association, for example, emphasized the need to identify indicators plausibly related to ecological change as early warning or sentinel conditions to be monitored (CPHA, 2015). This followed a recommendation from the Public Health Agency of Canada to adopt a One Health approach when developing preventative public health systems for climate change adaptation (CPHA, 2015). Although there is grossly insufficient data from which to nominate the most effective, efficient and reliable animal signals of public health risk or vulnerability related to changing climate (Stephen and Duncan, 2017), there is a growing opinion that animals, particularly wildlife, could provide early warning of public health concerns related to climate change. This is, in part, due to their proven value as sentinels in other early warning situations (e.g. emerging infectious disease, pollution). For example, the impacts of air pollution on dairy cattle are more pronounced than in people, suggesting these production animals may be a good sentinel (Cox *et al*., 2015, 2016). Given the projections for changing distributions and burdens of pathogens and pollutants in the face of climate change, the role of animals as bio-indicators is anticipated to increase. There is a long history of animals serving as bio-sentinels for the effects and indicators of the distribution of environmental pollutants and pathogens (Rabinowitz *et al*., 2009). Realizing the potential of One Health early warning signals will require effective communication between the animal and human health systems for timely and trusted information sharing (Zinsstag *et al*. 2018).

Although infectious diseases, especially vector-borne, predominate One Health concerns about climate change, a One Health sentinel system needs to look more broadly. Changes in temperature, precipitation and weather patterns will not only alter pathogen and parasite epidemiology, but also the pathways, persistence and concentrations of pollutants entering the environment via air and ocean currents will increase with climate change (Burek *et al*., 2008). Increasing use of pesticides to control invasive pests, and the release of chemicals from sediments from melting ice and permafrost are raising concerns about changing exposure and effects of pollution, especially for children (USEPA, 2013). Animals, wild and domestic, have a well-established history as biologically meaningful sentinels of health risks from environmental pollutants. Wildlife, for example, have thyroid and other endocrine disorders, metabolic diseases, altered immune function, reproductive impairment, developmental toxicity, genotoxicity and cancer all linked to environmental contaminants (Stephen and Duncan, 2017). Changes in population ecology may also forewarn of impeding health impacts for society. Changes to fish and wildlife migration routes, population size, body condition, and infection and contamination status and their abundance and distribution may foreshadow impeding food security crises for poor and vulnerable populations that rely on hunting and fishing as their main protein sources. The nature, amount and variability in biodiversity determines the sustainability and flow of ecosystem services that are key determinants of a community's capacity to adapt to future health challenges, whether they arise from novel pathogens, emerging non-communicable diseases or loss of ecological services (Keune *et al*., 2013). When the ecosystems services, economic contributions and food provided by animals become compromised, so too does the capacity for human communities to cope with shocks and changes we anticipate to see in the Anthropocene (Stephen *et al*., 2019). Limiting climate change surveillance systems only to infectious and parasitic diseases would do society a great disservice given the multitude of impacts animals have on our well-being.

We should not only conceive of One Health climate change sentinel systems to be one way. Better understanding of the role of social change on the vulnerability of domestic animals and wildlife is also needed through surveillance of social changes or environmental changes of human origin. Animal health organizations should expand their surveillance systems from their current preoccupation with changing animal diseases or changes in animal hazards to a health intelligence or health observatory model that also includes reconnaissance of animal, social and environmental settings in order to achieve better situational awareness of shifting vulnerabilities in animal populations. Climate change intelligence, in this instance, could be considered the process of generating, collecting and analysing a variety of information to foster collaboration and consultation through innovation in surveillance, information exchange, research, and response to protect, promote and support decisions affecting animal health and its associated social values. A recent example of the use of a health intelligence model can be found in the Pan-Canadian Approach to Wildlife Health, approved as a guiding document by Canadian federal, provincial and territorial governments in 2018 (Stephen, 2019).

Enhanced collaboration between human and animal health sectors is also necessary to avoid or cope with health impacts that are novel or unanticipated. Being aware of what is happening in one sector may motivate action in another sector before significant harm ensues (PHAC, 2017). This is a foundational premise of One Health and underlies much research and many programmes that look for early warning clues in animal health signals. Knowing what is being done in one sector can also help avoid conflicts or negative synergies with actions in another sector. For example, local environmental scarcity that may be affected by forestry, agriculture or environmental policies has been linked to high-risk activities that can confound infectious diseases control programmes, as was seen for HIV and Ebola virus outbreaks (Hunter *et al*., 2011; Olivero *et al*., 2017). Intersectoral collaborations can also reduce harm from surprises when it builds resilience across species to better cope with the unexpected. Human communities are better able to recover from disasters, such as extreme weather, in situations where natural resources are not degraded (Miller *et al*., 2006). This is reflected in the Sendai Framework for Disaster Risk Reduction, which recommends sustainable use and management of ecosystems to preserve ecological relationships and functions that reduce risks and support resilience (UN, 2015).

There are also opportunities for efficiencies in the sharing and delivery of health services. Co-delivery of veterinary and medical services have been found to result in more effective and efficient health services for all species involved (e.g. create efficiencies in low resource areas) (Schelling *et al*., 2005). As the health challenges due to climate change expand and are compounded by additional stressors due to other global trends such as the spread of invasive species, urbanization and landscape change, resources for health services will become more scarce. The likelihood of innovative climate change responses will increase as leaders diversify their professional network and in doing so increase their exposure to non-redundant information, skills and support (Tortoriello *et al*., 2015). Although there is general agreement about the complex and co-dependent interplay among individual, environmental, ecological and social factors influencing resilience to climate change, there is a disconnection between the multiple policies, practices and perspectives influencing preparedness and adaptation capacity. There is a need for a more unified set of guidelines to comprehensively promote climate change resilience by concurrently and collaboratively tending to the determinants of resilience, for each other, our communities, our animals and the natural environment. There is an important leadership opportunity for the One Health sector to champion and bridge this cross-sectoral gap (see Pelican *et al*., Chapter 15, this volume).

Framing climate change in a health context can be an effective way to improve climate change literacy and empower people to act. Empowering people to act in response to climate change goes beyond documenting and disseminating alarms about the unsustainability of the current trajectory of humanity. Regardless of political orientation, Americans across the political spectrum were found to be receptive to information, and mitigation-related policy actions, about climate change when framed based on its health impacts (Maibach *et al*., 2010) suggesting that this approach could better unite people. Using narratives, or storytelling, to convey a message can increase understanding of the topic and be both engaging and interesting (Dahlstrom, 2014). Within a climate change conversation, individuals may more easily identify with the framing of issues around health, which could facilitate behavioral changes. Similarly, public health framing arouses hopeful emotions about climate change (Myers *et al*., 2012). Improving people's access to information and their capacity to use it effectively is key to empowerment. Sharing messaging and best practices in climate change literacy across sectors may reduce the time between knowledge generation and action by helping people obtain, process and understand information and services needed to make appropriate decisions. Given the role of individuals in creating and solving climate change problems for health, encouraging public values and behaviour towards climate change action represents a legitimate but currently underutilized One Health activity.

Coordinated and integrated messaging between health and environment agencies may help expand citizens' climate change literacy. These messages, however, need to focus more on empowering rather than overwhelming people. Too often stories of health and climate change focus on the threats to us, whether through pandemics, extreme weather, pollutants, sea level rise or similar catastrophes. Messages that emphasize the dire straits we are in, the global reach of influences degrading the environment and the failure to offer tangible examples of local and personal actions that can make positive changes disempower people from acting. Helping people know and understand how ecosystem functions and biodiversity supports climate change adaptation is an essential change in the narrative if we are to empower citizens by giving them the sense that they can influence events and outcomes important to them. One Health organizations can help reshape social norms and encourage actions that are beneficial to people, animals and environments by influencing public perceptions of health and wellness as a codependent relationship with a healthy Earth.

Moving Forward

Despite climate change being arguably the most important challenge of the 21st century, One Health engagement and leadership on this issue can be hard to find. Visionary leadership is needed to align a diverse professional community with partners who need to collaborate on climate change responses, adaptation and mitigation. The One Health community needs to better situate its concerns and provide its expertise for policy makers and managers responsible for climate change planning and action. This will be best achieved through alliances between health, agricultural, conservation, fisheries and related groups to make shared plans, statements and commitments to action. Cross-sectoral, collective action to address shared determinants of health and resilience could be achieved by moving One Health beyond infectious diseases to collaboration on reciprocal care for ourselves, animals and ecosystems.

While there is not enough experience or published evaluations to define best practices in collaborative climate change action, there is enough information from other sectors and problems to inform action. Fundamental to the intersectoral approach to climate change and health is the development of good teams. Such teams require not only human and animal professionals, but also more representation from the environmental sector (Stephen and Karesh, 2014; Barrett and Bouley, 2015; Destoumieux-Garzón *et al.*, 2018). Defining a common goal has been proposed as the 'first and foremost' step to achieve greater collaboration between human and animal healthcare professionals (Eussen *et al.*, 2017). By focusing on factors that can benefit a range of species through multiple pathways, there is greater likelihood that teams will identify areas of commonality. Other components of developing strong interdisciplinary teams include the development and fostering of both formal and informal relationships built on trust and respect (Anholt *et al.*, 2012).

There is a theoretical basis and growing opinion that One Health can help to inform public health decisions on climate change risk management. There are, however, two critical gaps to overcome before the value of One Health can be fully exploited for climate change. First, a systematic way is needed to collect, integrate and communicate the direct and indirect effects of climate change at the human–animal–environment interface. Health threats due to climate change will be associated with interconnected economic, social and environmental changes. Understanding these changes is crucial for preparedness and subsequent prevention and control actions. New tools for surveillance such as environmental scanning, foresight programmes and horizon scanning are being promoted to collect and assess information for rapidly responding to changing risks and to anticipate drivers of new threats (Brookes *et al.*, 2015). Intelligence, Surveillance, Reconnaissance (ISR) models are one example of an approach that could increase the likelihood that One Health information systems can inspire actions in advance of harms. This approach combines traditional surveillance in populations and locations of interest with targeted and contextual information acquired on specific issues in populations to identify local situations or populations to prioritize for climate change action. This approach works best when it is designed based on strategies and objectives rather than focused on producing outputs for known or fixed targets (Brown, 2014). Just as the war on terrorism required military intelligence to shift to more dynamic and contextual methods, climate change is driving health surveillance to be more flexible and adaptable to changing and unexpected conditions. Transparent and repeatable methods are needed to identify and prioritize threats and make recommendations on higher risk situations and settings upon which to target resources.

Second, new attempts to deploy One Health concepts and methods in climate change response should be accompanied by evaluation. Literature on best practices for One Health to affect change in the climate change realm is exceedingly rare. Cross-sectoral co-learning will require bridging agents embedded within an agency to facilitate transdisciplinary evaluations (Berger-González *et al.*, Chapter 6, this volume). As with many trans- and interdisciplinary initiatives, evaluating climate change programmes will be challenged by: (i) the lack of universally accepted indicators or thresholds for success; (ii) the delays between actions and responses; (iii) the role of local context and capacity to influence programme implementation and success; (iv) the challenge of separating climate action from action on other drivers of harm and vulnerability; and (v) the lack of research and investment in evaluation. However, without understanding the fiscal, practical, social and scientific usefulness of a programme, it will be hard to make evidence-based recommendations for effective One Health actions.

Continued education of health and allied professionals and the public is needed. One of the four key messages from the *Lancet Countdown 2018 Report* was that climate change must be understood as a central public health issue in order to deliver an accelerated response (Watts *et al.*, 2015). Overall, most human health professionals believe that climate change poses a significant public health threat (Pandve and Raut, 2011; Villella, 2011; Nigatu *et al.*, 2014; Sarfaty *et al.*, 2014a,b,c, 2016; Wei *et al.*, 2014; Hathaway and Maibach, 2018), and the topic of climate change is being integrated into curricula and other educational opportunities (Green Ei *et al.*, 2009; Bell, 2010; Veidis *et al.*, 2019). In contrast, there is little formal education on climate change in the veterinary curricula, despite a strong interest on the part of students (Pollard *et al.*, 2020). Climate scientists, conservationists, urban planners and the environmental sector should understand, in turn, that they hold a valid understanding of health implications of climate change for people, animals and ecosystems.

Leadership is needed. Medical, veterinary and public health associations have a leadership role to play and are acting to make climate change and health a priority (Pelican *et al.*, Chapter 15, this volume). Stephen *et al.* (2019), however, noted a distinct lack of climate change leadership in the veterinary sector. The OIE's Sixth Strategic Plan saw the need to understand the relationships between climate change and ecosystem health, biodiversity loss and the spread of diseases in order to address its strategic objective of securing animal health and welfare by appropriate risk management (OIE, 2015). However, that plan seemed mainly concerned with changing risks of vector-borne diseases. The Food and Agriculture Organization of the United Nations, in 2019, emphasized support for countries to mitigate and adapt to the effects of climate change through research-based and practical programmes and projects (Stephen *et al.*, 2019). Websites of many veterinary associations in the Global North failed to list climate change as a priority for their association, although there were signs of change. The Canadian Veterinary Association planned to assemble a summit on climate change in 2020 and the World Veterinary Association and Caribbean Veterinary Association have included climate change in recent past meetings. The Canadian Medical Association and the Canadian Public Health Association have jointly called for the implementation of recommendations per the *Lancet Countdown on Health and Climate Change*, including climate and health-related surveillance, education, communication and funding (Howard *et al.*, 2018). In 2019, the Australian Medical Association declared climate change a health emergency (AMA, 2019). Binding these various interests and initiatives into a coherent and integrated approach is an important leadership role for One Health organizations.

Conclusions

Even though there are gaps in our knowledge about how One Health can most effectively and efficiently help humanity, biodiversity and systems cope with climate change, the gap between knowing and doing is even wider and more difficult to breach. Closing the knowing-to-doing gap requires time, relationships and active processes to create linkages and knowledge exchanges between creators and users of information from multiple sectors and facilitating action on agreed upon goals. One Health might be most effective by taking a leadership role in promoting and sustaining cross-sectoral, collective action to address shared determinants of health and resilience for ourselves, animals and ecosystems (see also Pelican *et al*., Chapter 15, this volume). The Lancet Commission recommended multisectoral government-wide strategies to address climate-related health threats, recognizing health professionals as leaders in this battle (Watts *et al*., 2015). One Health is well suited to bring those and other professions towards a common agenda of climate change adaptation and mitigation for health.

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18 Emergence of Antimicrobial Resistance and Interaction Between Humans, Animals and Environment

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Introduction

The global emergence of antimicrobial resistance (AMR) is a threat to human health (World Health Organization, 2018) and requires new approaches to avoid infections where no active antimicrobial agents are available for treatment. Multidrug-resistant organisms (MDROs) have become common in healthcare settings, in particular in acute care hospitals, because of their severity of illness of patients and the high-risk environments for the spread of pathogens. Across industrialized countries, between 5% and 10% of all hospital inpatients will contract some form of healthcare-associated infection (HCAI), leading to added morbidity and mortality. For example, 'MDRO', methicillin-resistant *Staphylococcus aureus* (MRSA), doubles mortality as well as cost for treatment compared with methicillin-susceptible *S. aureus* (O'Neill, 2016), and MRSA adds up to the overall infections also by methicillin-susceptible *S. aureus*. Many resistance patterns may render pathogens as MDROs: the most common mechanisms are plasmid-mediated inactivation by β-lactamase, target modification or porin loss.

The average age of populations is increasing worldwide as well as the number of immunocompromised patients, either by treatment for autoimmune diseases (e.g. anti-TNF drugs for rheumatoid arthritis) or by immunosuppressive therapy, e.g. after transplantation. These patient groups largely survive longer thanks to effective antimicrobial drugs as prophylaxis or treatment, drugs that may render ineffective in close future (O'Neill, 2016).

Low- and middle-income countries are affected by MDROs, with limited resources, poor sanitation and faecal contamination (animal and human) of soil and water, but also with over-the-counter antibiotics and usage of low-dose antibiotics for growth promotants, all contributing to high rates of AMR (Gilbert, 2017).

These countries are commonly targets for tourists, where they acquire MDROs during travel. Up to 80% of travellers returning to Switzerland after travel to the Indian subcontinent are colonized with extended-spectrum β-lactamase-producing *Enterobacterales* (ESBL-E) (Kuenzli *et al.*, 2014). Figure 18.1 shows prevalence of multidrug-resistant bacteria carriage in returning patients according to the geographic region they visited prior to hospitalization.

In the European Union (EU) in 2015, the European Centre for Disease Control and Prevention (ECDC) calculated there were 671,000 infections with antibiotic-resistant bacteria and 33,000 attributable deaths (Cassini *et al.*, 2019; Tacconelli and Pezzani,

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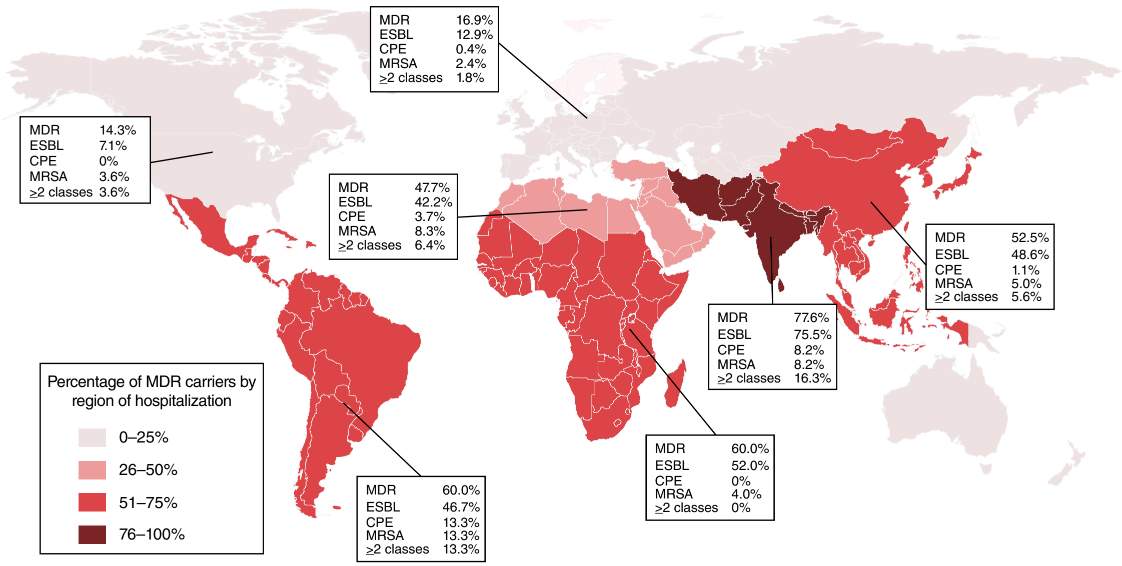

Fig. 18.1. Prevalence of multidrug-resistant bacteria carriage in returning patients according to the geographic region of their prior hospitalization. MDR, multidrug-resistant bacteria; MRSA, methicillin-resistant *Staphylococcus aureus*; ESBL, extended-spectrum β-lactamase-producing *Enterobacteriaceae*; CPE, carbapenemase-producing *Enterobacteriaceae*. From Khawaja *et al*., 2017, reprinted with permission.

2019) based on the Europe-wide prevalence study on HCAIs. The O'Neill report estimates that by 2050, 10 million people could die each year from AMR unless the spread of antibiotic resistance could be stopped (O'Neill, 2016). Similarly, the World Economic Forum Annual Meeting 2014 in Davos, Switzerland, considered the threat of MDROs as high and likely to occur, and therefore a threat to society (World Economic Forum, 2014). Figure 18.2 illustrates model estimates of the burden of infections with selected antibiotic-resistant bacteria of public health importance in disability adjusted life years (DALYs) per 100,000 population, in the EU and European Economic Area in 2015.

One Health and AMR

Because of the inextricable linkage of humans, animals and their environment, with regard to the use of antibiotics, the fight against emergence of AMR is a prime example for One Health and antibiotic stewardship, being a crucial component to combat its emergence and spread. How can we elicit an incremental benefit (Zinsstag *et al.*, Chapter 2, this volume) of a One Health approach to AMR?

The human–animal–environmental nexus

Antibiotic overuse, inadequate prescribing (Kakkar *et al.*, 2017), massive use to promote growth in livestock production and agricultural use are considered as the most important drivers. MDROs can spread within healthcare institutions as well as being disseminated through ground and surface water (O'Neill, 2016; Anonymous, 2018).

Humans, animals and the environment are in close contact and interconnected in a complex way (Fig. 18.3), but effective causal pathways and the direction of spread between hosts and between commensal (microbiome) and pathogenic bacteria are not well understood (Woolhouse *et al.*, 2015; Hu *et al.*, 2016; Anonymous, 2018).

Development of new antibiotics is stagnating, since the net present value of research argues more towards development of drugs against cancer or chronic diseases. In addition, AMR bacteria are found in drinking water in developing countries (Collignon and McEwen, 2019), mainly as a result of poor sanitation. Nevertheless, it is also necessary to have better incentives to promote investment in developing effective antimicrobial drugs (O'Neill, 2016).

Recommendations to reduce antibiotic use through improving hygiene, avoiding unnecessary

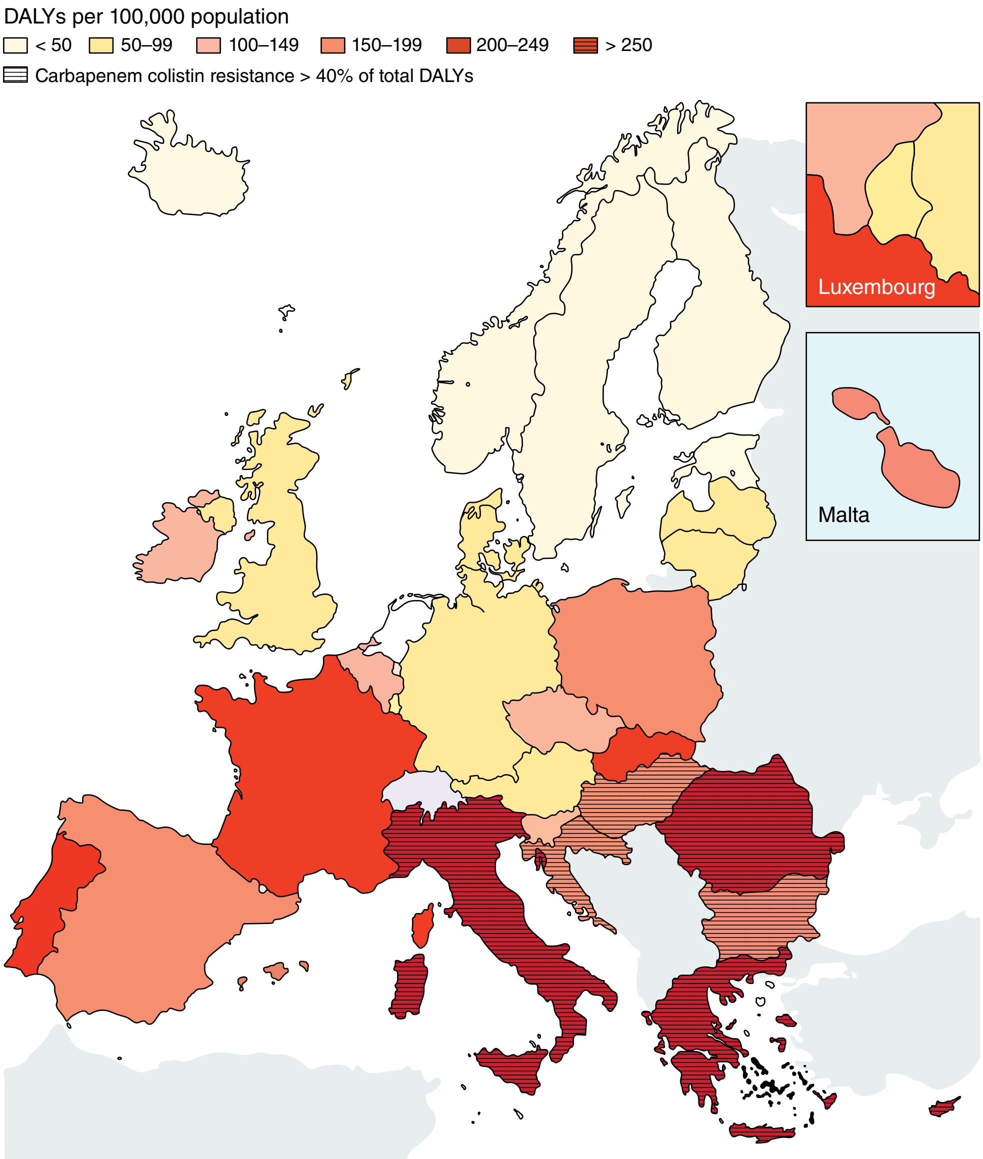

Fig. 18.2. Model estimates of the burden of infections with selected antibiotic-resistant bacteria of public health importance in disability adjusted life years (DALYs) per 100,000 population, in the European Union (EU) and European Economic Area in 2015. From Cassini *et al*., 2019, reprinted with permission.

use in agriculture and human medicine, and improving surveillance and rapid diagnosis are crucial to fight MDROs (O'Neill, 2016), but their specific leverage and effectiveness as systemic drivers to interrupt emergence and transmission of AMR between humans, animals and the environment and cost sharing between sectors are not known (Woolhouse *et al*., 2015; Larsson *et al*., 2018; Aenishaenslin *et al*., 2019).

Information on how bacteria and genes reach the environment and evolve does not translate to deduce effects on human health outcomes (Larsson *et al*., 2018). Quantitative attribution of antibiotic resistance to specific transmission routes in specific

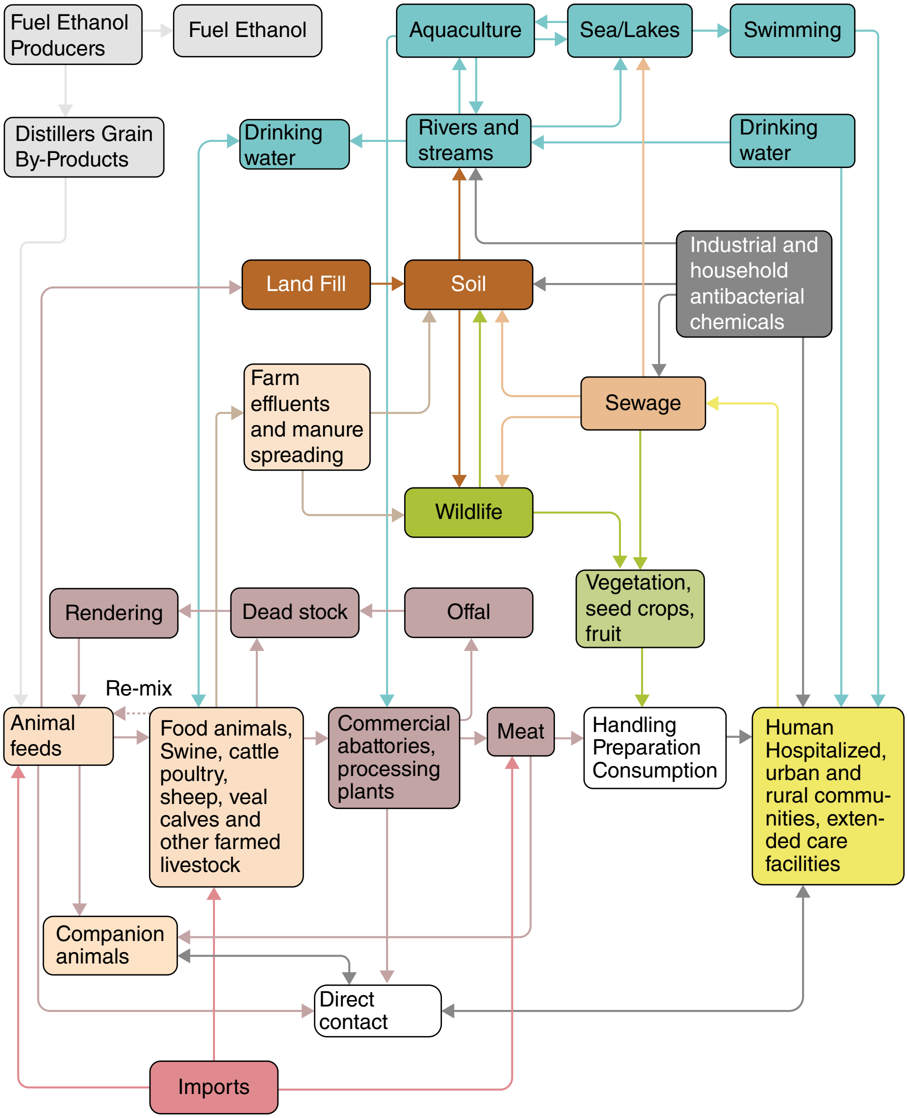

Fig. 18.3. Adapted flow chart of antimicrobial resistance of the Canadian Integrated Programme for Antimicrobial Resistance Surveillance. From Zinsstag *et al.,* 2011, reprinted with permission.

contexts is largely unknown (Larsson *et al.*, 2018). Most AMR studies measure antibiotic use during point prevalence studies on HCAIs, are descriptive and limited in time and scale and are not sufficient to build an overarching theoretical framework of resistance dynamics (Larsson *et al.*, 2018).

In Gothenburg, Sweden in September 2017, The Joint Programming Initiative on Antimicrobial Resistance (JPIAMR) (see www.jpiamr.eu (accessed 15 August 2019)) described the following critical knowledge gaps: (i) the relative contributions of different sources of antibiotics and antibiotic resistant bacteria into the environment; (ii) the role of the environment, particularly the anthropogenic inputs, on evolution of resistance; (iii) the overall human and animal health impacts caused by exposure to resistant bacteria from the environment; and (iv) the efficacy of technological, social, economic and behavioral interventions to mitigate environmental antibiotic resistance (Larsson *et al.*, 2018). Similarly, Woolhouse *et al.* (2015) called for a sufficiently detailed, quantitative understanding of the dynamics of bacteria, drugs and resistance determinants in multiple host and environmental compartments to make meaningful decisions on AMR control.

Single discipline studies fail to identify the most effective methods to contain MDROs. A lack of theory driven by One Health studies makes it almost impossible to identify effective mitigation strategies (Rousham *et al.*, 2018), calling for a One Health perspective covering animals, humans and the environment simultaneously (O'Neill, 2016). The Interagency Coordination Group on AMR (IACG), recognizes that drivers of AMR reside with humans, animals, plants, food and the environment, thus recommending integrated One Health approaches for control, especially in low- and middle-income countries (IACG, 2018, 2019). AMR is therefore not only a quintessential One Health issue (Robinson *et al.*, 2016), but One Health is an *essential prerequisite for a systemic understanding of AMR* acquisition and spread and for identifying effective control strategies.

Examples of AMR in Hospital Germs Circulating Between Animals and Humans

Methicillin-resistant *Staphylococcus aureus* (MRSA)

Staphylococcus aureus (S. aureus) is part of the commensal flora of humans and animals, colonizing 20–40% of the human population, mainly in the nares. Colonized individuals are vulnerable to develop *S. aureus* infection with invasive medical devices or if their immune system is compromised either by underline disease or by treatment (Dweba *et al.*, 2018; Lee *et al.*, 2018).

One of the most important causes of antimicrobial-resistant pathogens currently worldwide remains MRSA. MRSA adds to the overall burden of *S. aureus*, rather than replacing methicillin-susceptible *S. aureus* – luckily several new antibiotics specifically against MRSA are coming into the market (World Health Organization, 2017; Dweba *et al.*, 2018; Heim *et al.*, 2018; Lee *et al.*, 2018). MRSA is not new: it became a public concern in the 1960s, originally mainly observed as a nosocomial pathogen (hospital-associated MRSA or HA-MRSA). The emergence of MRSA infections in the 1990s among previously healthy individuals in the community, but without links to health-care settings, introduced a new form, called community-associated MRSA (CA-MRSA) (Paterson *et al.*, 2014). CA-MRSA has also spread over time to health-care settings, and clones of MRSA may even replace the HA-MRSA (Bal *et al.*, 2016). MRSA can not only colonize humans but also a wide range of mammal species including pets, livestock and wild animals, and can subsequently cause, for example, skin and soft tissue infections, bacteremia or pneumonia among humans (Lee *et al.*, 2018), bovine mastitis among dairy cattle or lameness in poultry (Weese, 2010; Paterson *et al.*, 2014). Animal welfare and the economic interest are relevant considerations regarding MRSA in animals, but animals are also important as a reservoir for zoonotic infection of humans, where exposure to livestock introduced a third epidemiological form of MRSA, livestock-associated MRSA (LA-MRSA) (Graveland *et al.*, 2011a; Paterson *et al.*, 2014). However, latest studies are finding a blurring of this epidemiology and possible transmission of LA-MRSA between humans (Bal *et al.*, 2016). MSRA in Swiss fattening pigs linearly increased from 2009 (2%) to 2017 (44%), with the largest increase from 2015 (25.7%) (European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDPC), 2019) and poses an increased zoonotic risk, as it was shown that higher regional livestock concentration was correlated with higher colonization rates of humans with LA-MRSA. However, the study found a much lower transmission rate for LA-MRSA than for non-LA-MRSA (van de Sande-Bruinsma *et al.*, 2015).

Clinical presentations as well as risk factors for developing infection vary between HA-MRSA, CA-MRSA and LA-MRSA strains (Lee *et al.*, 2018). Transmission of HA-MRSA is mainly related to poor infection control, since MRSA is transmitted by direct contact. Similarly, frequent sources of CA-MRSA are common items such as from fitness centres, shared towels and direct contact between individuals. The impact of LA-MRSA carriage on otherwise healthy persons appears to be low and severe infections due to LA-MRSA are possible but seem to be rare (van de Sande-Bruinsma *et al.*, 2015; Goerge *et al.*, 2017).

Sequence types (STs) of *S. aureus* can be grouped into clonal complexes (CCs) by their similarity to a founder allelic profile (genotype) to determine their genetic relatedness, or for even more detail by next generation sequencing, and this therefore enables investigation of the geographical spread of different clones (Aires-de-Sousa, 2017; Lee *et al.*, 2018).

In MRSA, the staphylococcal cassette chromosome *mec* (*SCCmec*) leads to resistance to most β-lactam antibiotics (Lee *et al.*, 2018). *SCCmec*, which is a mobile chromosomal element, carries the *mecA* or *mecC* gene and encodes for a specific penicillin-binding protein (PBP2a) (Liu *et al.*, 2016).

MecC MRSA epidemiology is not completely understood but it was shown that direct animal contact and zoonotic transmission are likely to be important in human infections with this organism (European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDPC), 2019). Recently, a *mec*B-based plasmid-encoded methicillin resistance has been identified in *S. aureus* (Becker *et al.*, 2018), but its resistance mechanism is yet to be clarified (Lee *et al.*, 2018). Fourteen known *SCCmec* types (I–XIV) have been identified to date and some types are primarily found in HA-MRSA (e.g. types I–III), others are primarily found in CA-MRSA (e.g. IV, V) or in LA-MRSA (e.g. XI) (Lee *et al.*, 2018; Urushibara *et al.*, 2020). However, as the classification into the different types becomes increasingly blurred, the distinction should not only be based on the *SCCmec* type (Bal *et al.*, 2016).

In contrast to CA-MRSA, several studies have shown that LA-MRSA sequence type 398 (ST398) and also HA-MRSA typically lack many previously identified toxin genes, including toxic shock syndrome toxin (TSST) and Panton-Valentine leucocidin (PVL) (van de Sande-Bruinsma *et al.*, 2015).

The most frequent livestock lineage in Europe is ST398 (CC398) MRSA, whereas in South-east Asia ST9 (CC9) MRSA is the most prevalent type (Bal *et al.*, 2016). This is in contrast to the spread of HA-MRSA, where few CC are circulating worldwide and are found in all continents (Aires-de-Sousa, 2017).

Professionally exposed people such as farmers or veterinarians have the major burden of colonization and infection with LA-MRSA. Studies reported a colonization rate of 24–86% in pig farmers and up to 37% in cattle and poultry farmers, including spread to their family members (Cuny *et al.*, 2009; Van den Broek *et al.*, 2009; Graveland *et al.*, 2011b; Richter *et al.*, 2012). Around 45% of veterinarians treating pigs were colonized with LA-MRSA in studies performed in Germany and the Netherlands (Cuny *et al.*, 2009; Verkade *et al.*, 2013). However, LA-MRSA cases with CC398 occurred in people with no documentation of exposure to livestock, suggesting a spillover of LA-MRSA to the community (Larsen *et al.*, 2015).

LA-MRSA strains are less transmissible to humans compared with CA-MRSA or HA-MRSA, which was also found in a study investigating the impact of LA-MRSA infections in a hospital, where no secondary contact case were found (van de Sande-Bruinsma *et al.*, 2015).

In addition, meat can be contaminated with MRSA in > 10% of investigated meat samples (Tang *et al.*, 2017), but LA-MRSA epidemiology indicates clearly that meat is currently not an important route of transmission (Bal *et al.*, 2016). Rather than from ingestion, MRSA acquisition can result after handling of raw meat, but is clearly not associated with transmission of LA-MRSA on a large scale (Bal *et al.*, 2016; Cuny *et al.*, 2019).

In contrast to other forms of MRSA, LA-MRSA can spread by the airborne route and can be found miles from an MRSA-contaminated barn on soil samples. Barns of pig and veal farms are often contaminated with LA-MRSA, a source for transmission to humans. Exposure to ST398 LA-MRSA in barn air seemed to be an important determinant for nasal carriage, particularly for the highly exposed group of farmers with close contact with animals (Bos *et al.*, 2016).

MRSA prevalence ranges from very low with < 5% in the Scandinavian countries to the highest rates in Asia and parts of America with 25–50% or even > 50% (Diekema *et al.*, 2001; Lee *et al.*, 2018). In general, less comprehensive data are generated from low- and middle-income countries (Lee *et al.*, 2018).

Due to lack of systematic surveillance in animals, the exact prevalence of CC398 is challenging to obtain (Bal *et al.*, 2016). In pigs a wide range of variation was found between seven reporting countries with lowest occurrence rates of 0.4% of animals that tested positive up to 90.4% (European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDPC), 2019).

The ECDC suggested that isolates from veterinary sources should be monitored to systematically map potential reservoirs and transmission pathways, thereby informing measures for prevention and control (Kinross *et al.*, 2017).

ESBL-E

ESBL-E have emerged in humans and animals, worldwide during the last few decades (Madec *et al.*, 2017), where wild as well as domesticated animals may serve as effective vectors for the dissemination of extended-spectrum β-lactamases (ESBLs) (Tyrrell *et al.*, 2016). ESBLs are enzymes mainly found in *Escherichia coli*, *Klebsiella pneumoniae* and *Enterobacter cloacae* (Zahar *et al.*, 2015), and these bacteria are mainly found in the digestive tract (Woerther *et al.*, 2013).

Similar to MRSA, infections with ESBL-E are associated with higher mortality rates and hospital costs compared to infections with susceptible organisms (Colomb-Cotinat *et al.*, 2016). Asymptomatic colonization with ESBL-E is a strong risk for infection (Gorrie *et al.*, 2017).

Resistance is mostly mediated by acquired ESBLs, which can hydrolyse almost all β-lactam antibiotics (Farra *et al.*, 2016). Among a wide range of enzymes – predominantly SHV, TEM and CTX-M, CTX-M ESBLs are the most common in Europe (Woodford *et al.*, 2011; Woerther *et al.*, 2013).

In Asian countries, CTX-M-14 predominates in humans, pets and poultry. This could indicate cross-contamination or a common third source (Madec *et al.*, 2017). In Europe, CTX-M-15 predominates in humans, whereas in animals CTX-M-1 is most frequently seen (Madec *et al.*, 2017).

ESBL resistance genes are usually located on mobile extrachromosomal genetic elements called plasmids (Carattoli, 2011). Plasmids can transfer between strains, species and genera and therefore spread between patients in hospitals and the community, including via a contaminated environment (Otter *et al.*, 2019).

ESBL-E were first detected in human medicine, but have been found recently in companion animals and increasingly in food-producing animals as well (Carattoli, 2008; Smet *et al.*, 2010; Ewers *et al.*, 2011). Foodborne transmission of ESBL-E to humans is still under debate, and the burden of animal reservoirs of ESBLs on human health is not yet determined (Madec *et al.*, 2017; Day *et al.*, 2019).

High rates of ESBL producers were shown in food-producing animals, prominently in chicken faecal samples (63.4%), where healthy swine, cattle, sheep and chicken at slaughter were screened for the occurrence of ESBL-E (Geser *et al.*, 2012). To prevent transmission of ESBL-E through food, cooking and proper hand hygiene are crucial. A study found ESBL *E. coli* on 50% of gloves after preparation and on 12% of cutting boards, which highlights the importance of hand hygiene compliance also in the community setting (Tschudin-Sutter *et al.*, 2014).

The spread of multiresistant *E. coli* ESBL strains were isolated not only from humans, but also from pets, livestock and food products as well as from river and lake water samples (Woodford *et al.*, 2011; Zurfluh *et al.*, 2013).

However, a recent study compared ESBL *E. coli* from human bacteraemias with those from human faeces, sewage, food, slurry and animals across five regions in the UK (Day *et al.*, 2019). These workers found that ESBL *E. coli* strains of ST131 dominated in bacteraemias, whereas the same ST131 was also most frequently found in human gut and in sewage. In contrast only two ST131 isolates were found from animal sources, from chicken meat and chicken surveillance. The most prevalent human ESBL *E. coli* types were rare in animals, meat and slurry (Day *et al.*, 2019). By contrast, the top sequence type in meat, which is ST602, particularly in chicken, was not recovered in human bacteraemias and was only found in two human faecal samples. In conclusion, non-human reservoirs made little contribution to invasive human disease and for human-adapted ESBL *E. coli* the human-to-human oral–faecal route was emphasized as the major transmission route (Day *et al.*, 2019).

It is important to consider that different *E. coli* populations might carry identical ESBLs through horizontally acquired gene transfer via plasmids (Madec *et al.*, 2017; Mughini-Gras *et al.*, 2019) that renders tracing of transmission very difficult. There is evidence that horizontal gene transfer occurs between different ESBL *E. coli* strain types over time, where even small cryptic plasmids seemed to move between different strains in the microbiota (Brolund *et al.*, 2019). This exchange of mobile genetic elements in combination with increased resistance rates in animals and the environment should be considered as a risk for developing resistance in human-adapted ESBL-E.

In order to quantify the attributable sources of community-acquired carriage of ESBL *E. coli* the resistance genes were investigated from human, animal, food, and environmental sources (Mughini-Gras *et al.*, 2019). Community-acquired ESBL *E. coli* were around 60% attributable to human-to-human transmission in the open community, whereas one-third were attributed to non-human sources (Mughini-Gras *et al.*, 2019). Molecular relatedness between different reservoirs were also quantified in another study, where gene distributions from people in the general and clinical population had higher similarities to those from human clinical settings, indicating a high human-to-human transmission. Furthermore, high similarities of gene distribution was also found between humans and sewage but also in surface water and wild birds, suggesting contamination of the environment with human wastewater. In contrast, lower gene similarities were found between people from general population and livestock or food reservoirs (Dorado-Garcia *et al*., 2018).

Human-to-human transmission within households has also been shown in a study investigating import and spread of ESBL-E by travellers to countries outside Europe, North America and Oceania (Arcilla *et al*., 2017). ESBL-E acquisition rate was 34.4% of travellers and long-term carriage after 12 months was seen in more than 10% of travellers. Furthermore, the probability of household transmission was 12%. The highest frequency of ESBL-E acquisition was found in 75.1% of travellers to southern Asia, highlighting the risk of ESBL-E spread globally by international travel (Arcilla *et al*., 2017). Although the absence of direct antibiotic pressure, wildlife is exposed to the environment directly, where wild birds can acquire resistant bacteria through contaminated water or feed and may be affected by colonization with multidrug-resistant bacteria (Kozak *et al*., 2009; Guenther *et al*., 2011; Alcala *et al*., 2016; Oteo *et al*., 2018; Zurfluh *et al*., 2019).

In investigations of rivers and lakes in Switzerland, ESBL-E were found in 36.2% of water samples, particularly in urban areas, with no positive results from 1000 m above sea level highlighting the association of ESBL-E occurrence with anthropogenic activities (Zurfluh *et al*., 2013).

Different studies performed in Europe showed that wild birds are colonized with ESBL-producing *E. coli* and may represent a reservoir for resistant bacteria (Guenther *et al*., 2010, 2011; Arnold *et al*., 2016; Oteo *et al*., 2018).

A study performed in Spain found the most important ESBL types in wild birds were also the most important ESBL types in the Spanish human population (Oteo *et al*., 2018). This is particularly a public health concern, as wild birds can disseminate resistance genes through migration over long distances, and it is one of the explanations for the finding of antimicrobial drug resistance genes even in the most remote places on Earth, such as the Arctic (Sjolund *et al*., 2008).

The global increase of ESBL-E prevalence in humans and in animals poses a risk of cross-contamination between different reservoirs (Madec *et al*., 2017).

Evidence of Environmental–Animal–Human AMR Exchange

Acquisition of the human and animal intestinal microbiome and resistome

It is debated whether the *human* intestinal microbiome, the symbiotic intestinal bacterial flora at birth, reflects the amniotic fluid microbiome (Francino, 2014; Stinson *et al*., 2019) and, depending on the mode of delivery at birth, either the mother's vaginal or human skin (caesarian section) microbiota (Francino, 2014). In the first weeks, colonization is strongly dominated by a few taxa (Francino, 2014). A markedly stable composition is established, with diversity increasing over about 3 years of life (Francino, 2014). The resident microbiota in healthy subjects forms a barrier preventing intrusion of foreign species (pathogens), a mechanism called colonization resistance. The term *resistome* was coined to denote the collection of all antimicrobial resistance genes (ARGs) in both pathogenic and non-pathogenic bacteria (Wright, 2007). The healthy paediatric gut resistome is established early in life, without selective pressure, and persists throughout childhood (Moore, 2013). It is debated if it already begins to develop in the intrauterine environment (Nogacka *et al*., 2018) and if the maternal gut resistome or the community are the major drivers (Moore *et al*., 2015).

In *livestock*, the acquisition of the microbiome and resistome is comparable to humans. Calves have a less diverse bacterial community at birth, which increases in complexity and diversity with growth, as a result of age and dietary changes (Malmuthuge and Guan, 2017). Lambs acquire core bacterial communities in the gut very early in life (Bi *et al*., 2019). Gut microbes of suckled lambs are mainly derived from the mother's teats, vagina and oral cavity, and ambient air (Bi *et al*., 2019). Antibiotics and other antimicrobials leave their mark on both the microbiome and host immunity (Relman and Lipsitch, 2018). However, calves are frequently removed from the mother for economic reasons, possibly interfering with development of a diverse microbiome.

Acquisition, attribution and spread of the intestinal resistome

ARGs are both an ancestral natural phenomenon (Relman and Lipsitch, 2018) independent from antibiotic usage, and an acquired phenomenon, observed in clinical isolates after prolonged exposure to antibiotics. AMR is acquired by clonal spread of bacteria or by horizontal gene transfer (HGT) (i.e. by plasmids), which have been also denoted 'epidemic plasmids' because of their capability for self-transmission (Rozwandowicz *et al*., 2018). Comprehensive genomic characterization of human pathogens shows that HGT of pre-existing genes contributes to the majority of current resistance problems generated by antibiotic use (Andersson and Hughes, 2017). HGT of ARGs is shaped by phylogeny (Forsberg *et al*., 2014; Hu *et al*., 2016) and ecology (Smillie *et al*., 2011), but a comprehensive systemic understanding of the major drivers of ARG transmission and the direction of spread between the environment, animals and humans is still lacking (Hu *et al*., 2016). Mobile ARGs mainly exist in four bacterial phyla: (i) *Proteobacteria*; (ii) *Firmicutes*; (iii) *Bacteroidetes*; and (iv) *Actinobacteria* (Stewardson *et al*., 2016). The tetracycline resistance genes, *tet(M)* and *tet(Q)*, and the integron-associated sulfonamide resistance gene, *sul1*, are the top three widely transferred mobile ARGs on the bacterial species level (Stewardson *et al*., 2016). IncF plasmids are the most frequently described plasmid type from human and animal sources (Rozwandowicz *et al*., 2018). Animals are a powerful mobile ARGs pool, shaping other resistomes (Pal *et al*., 2016; Stewardson *et al*., 2016).

AMR in low-income countries

AMR research in low-income countries is highly under-represented, although it is an important source of worldwide spread (Karanika *et al*., 2016; Rousham *et al*., 2018). In low- and middle-income countries, humans are mostly colonized with extended-spectrum β-lactamase *Escherichia coli* (ESBL-EC), which have dramatically increased in the last few decades, but factors associated with the acquisition of resistant bacteria in humans are not well established. Pathogens harbouring carbapenemase are an even greater threat to human and animal health than ESBL-E. Humans can acquire ARGs from soil and convey them to animals (e.g. carbapenemases) and animals can transmit ARGs to humans (Fig. 18.3) (Woolhouse *et al*., 2015). Food-producing animals provide large reservoirs of AMR through massive and uncontrolled use of antibiotics as growth promotors mostly in poultry, pigs and fish and to a lesser extent in the cattle and sheep industry (Woolhouse *et al*., 2015; Rousham *et al*., 2018). In small-scale farming antibiotics are more often used therapeutically (Rousham *et al*., 2018). ESBL-EC transmission from livestock to humans has been reported from China (Zheng *et al*., 2012). Livestock faeces, primarily poultry and pig, contaminates soil and water mostly with ESBL-EC, with *blaCTX-M* (Ma *et al*., 2012). Cattle farmers and their cattle carried phenotypically AMR-resistant *Salmonella* spp. in Ethiopia (Addis *et al*., 2011). Soil is an important ancestral source of AMR (Woolhouse *et al*., 2015), but humans also transfer AMR to the environment, for example quinolones (*qnr* genes) (Woolhouse *et al*., 2015).

Knowledge gap of a systemic understanding of AMR

An in-depth understanding of the trends and barriers for HGT of the mobile resistome between the environment, animals and humans is essential to predict emergence of antibiotic resistance (Hu *et al*., 2016). Very few studies assess AMR simultaneously in humans, animals, food and the environment, and those who do have a poor epidemiological planning (Dhaka *et al*., 2016) or assess only selected sections of the social-ecological system (SES) (Dulo *et al*., 2015). Only one study used a comprehensive SES design combined with a metagenomic analysis but sampled relatively few animals as a cross-sectional study with no clear conclusion on attribution or spread of AMR (Pehrsson *et al*., 2016). Knowledge on behaviours, practices and contacts within SES is very scarce and plays a central role in understanding acquisition and spread of AMR (Rousham *et al*., 2018). Knowledge of acquisition and spread between humans, animals and the environment is very fragmented with few integrated, longitudinal One Health studies undertaken and none so far using a birth cohort in humans and animals. A comprehensive elucidation of AMR acquisition and spread requires sufficient statistical power and representative sampling from human-livestock-environment contact networks, material flows and mapping of genes and bacteria by a metagenomic and bioinformatic assessment of clonal diversity to gather broad insight in shared ARGs and common sources of acquisition (Rousham *et al.*, 2018). Further, samples need to be collected over longer time periods within a geographical range covering all relevant host populations (Woolhouse *et al.*, 2015). This is the essence of the One Health approach: microbes are inextricably linked to the social lives of their human and animal hosts, and interventions to improve public and animal health must be designed in response to dynamic food cultures and food economies (Carruth *et al.*, 2017).

Added Value of One Health Integrated Antibiotic Resistance Surveillance

Towards a systemic One Health research agenda of AMR control

To understand acquisition, diversity and interspecies attribution and spread of AMR and of the whole resistome in humans and livestock in relation to their environment, food and social practices requires a systemic integrated One Health assessment characterizing the overall flows and processes depicted in Fig. 18.3.

The best way for such an assessment depends on the type of resistome, for example the skin, respiratory or intestinal microbiome, and the respective social-ecological context (Zinsstag *et al.*, 2011). This means in which ways are humans and animals in contact in urban and rural areas, livestock production systems, environmental sanitation, health systems, and the food supply (Fig. 18.3). For this, we expand One Health, limited to human and animal health, towards a broader concept of 'Health in Social-Ecological Systems' (HSES), to consider complex linkages between human and animal health and the environment within a SES, a well-established term in systems dynamics (Ostrom, 2007; Zinsstag *et al.*, 2011). Here, we propose two examples of integrated research approaches to assess the dynamics and spread of the intestinal microbiome.

1. Integrated material flow – quantitative microbial risk assessment of AMR

We propose to assess the circulation of AMR between humans and animals in relation to environmental sanitation, combining quantitative microbial risk assessment (QMRA) and material flow analysis (MFA) (Nguyen-Viet *et al.*, 2009). For example, Fig. 18.4 depicts the material flow of nitrogen in the environmental sanitation and agricultural system in a village in the Ha Nam Province in Vietnam (Nga *et al.*, 2016). The nitrogen MFA is a quantitative proxy indicator for the flow of faecal matter and thus the quantitative flow of AMR bacteria in the SES. Critical control points (CCP) of quantitative microbial risk (QMRA) of spread of AMR can be identified and quantified within the MFA system and consequently addressed as a targeted control strategy for the spread of AMR (Fig. 18.5). Subsequently, effects of interventions at the level of CCPs on the attribution and spread of AMR can be simulated using dynamic models of the coupled MFA-QMRA system.

HSES is conceptually clearly broader than One Health through explicit inclusion of the environmental and agricultural systems in addition to human and animal health. Specifically combining and extending the flow chart from Fig. 18.4 to Fig. 18.5 to an animal–human–environment flowchart we postulate an added value of a systemic understanding in terms of *attribution of pathogens and AMR in humans* along the established material flows between human, animal and environmental sources.

2. Acquisition and attribution of ARGs in humans and animals and their environment in cohorts of newborns in the first years of life

An integrated One Health birth cohort study approach may reveal how AMR is acquired and spreads between humans, animals and the environment in relation to microbiota composition in a way that can otherwise not be shown. To understand the acquisition and spread of AMR under the most 'natural' conditions, a study context with relatively little antibiotic use and low influence from adjacent urban areas which contaminate the watershed with ARGs could be chosen (Ergie *et al.*, 2019), thus exerting a low selective pressure, while maximizing the probability of the exchange, spread and enrichment between humans, animals and environmental sources like drinking water.

Conditions for assessing acquisition and spread of ARGs under low selective pressure are found in mobile pastoralist settings like the Somali Regional State of Ethiopia, where people live in very close relationship with their animals, without environmental sanitation and drinking the same surface water as their animals (shown in Fig. 18.6).

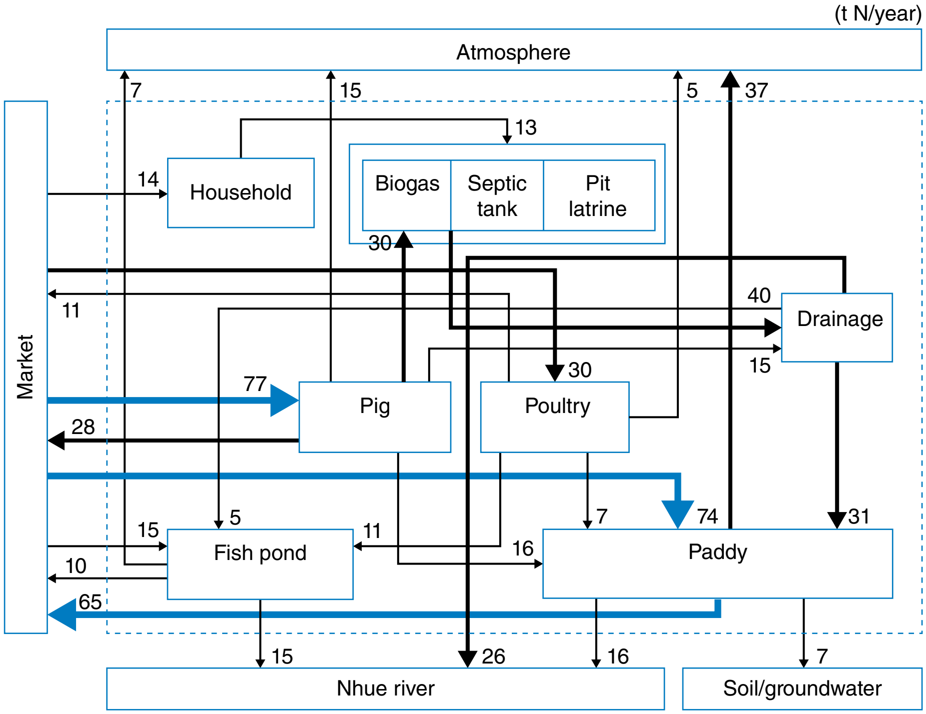

Fig. 18.4. Material flow analysis system of the environmental sanitation and agricultural system in the Hoang Tay commune, Ha Nam Province, Vietnam. From Nga *et al.*, 2016, reprinted with permission.

Such context represents a unique opportunity for the creation of a 'baseline' understanding on the spread of ARGs between humans, animals and the environment, which could not otherwise be generated. Faecal samples would be collected annually from a birth cohort of children, cow and camel calves, goat kids and donkey foals. Human and animal parents and, as depicted in Fig. 18.3, drinking water, milk and milk products, house floor, soil, and other environmental sources would also be sampled.

Shotgun metagenomics sequencing from extracted DNA from faecal samples allow microbiome species ARG identification. A microbial strain collection would further allow determining the presence of ARGs directly in given bacterial strains for identification of strains carrying yet unknown ARGs. Bioinformatic and biostatistical analyses of the microbiota data as well as of the resistome aim to clarify understanding of strain and horizontal gene transfer of ARGs in relation to colonization resistance.

The analysis of the causal evidence for the drivers of the ARG acquisition and attribution could be achieved from genomic epidemiological analysis identifying and assessing intra- and interspecies genetic closeness of specific ARGs. The acquisition of human, animal and environmental ARGs (e.g. a tetracycline resistance gene in humans) could be modelled as a system of coupled differential equations with several compartments for each host/environmental type.

Various methods to reduce antibiotic use (e.g. through improving hygiene, avoiding unnecessary use in agriculture, improving surveillance and rapid diagnosis, antibiotic stewardship and the development of new antibiotics) could be complemented by a One Health research agenda for the acquisition, spread and attribution of AMR in a given human–animal–environment system. Such One Health research could yield novel insight of the major drivers of AMR and consequentially lead to novel evidence-based policies for their prevention and control.

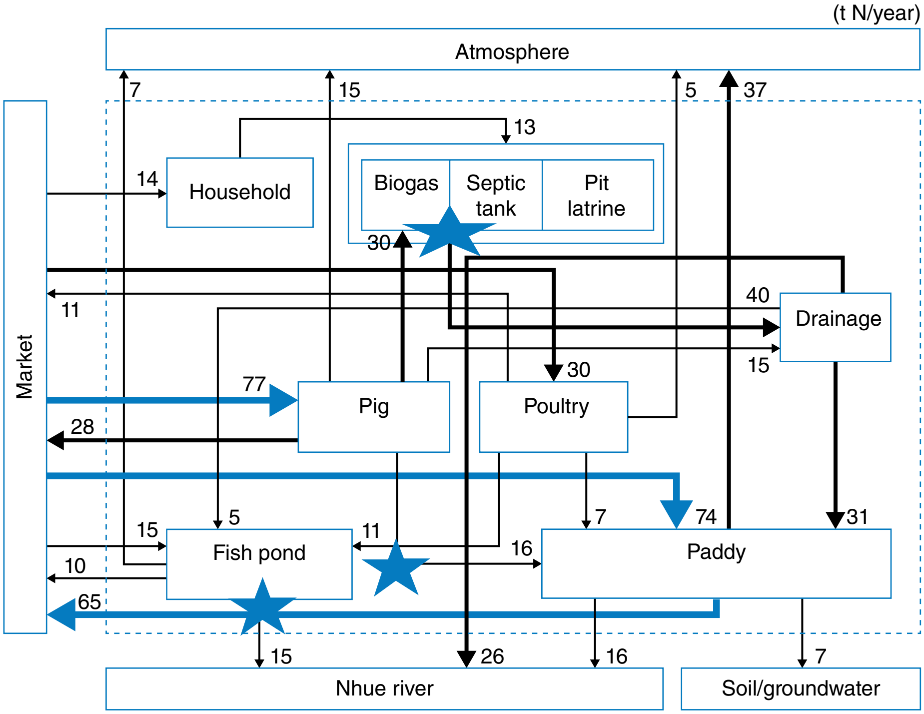

Fig. 18.5. Material flow analysis system of the environmental sanitation and agricultural system in the Hoang Tay commune, Ha Nam Province, Vietnam, with putative critical control points of AMR risk of spread marked with stars. Adapted from Nga *et al*., 2016.

Fig. 18.6. Mobile pastoralists in the Somali Regional State of Ethiopia collecting drinking water and watering their animals. Photo courtesy of J. Zinsstag.

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19 Integrated Rabies Control

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Introduction

Rabies is a classic zoonotic disease, infecting all mammal species. It is generally transmitted from saliva through a bite wound, leading to encephalitis with distinct, severe symptoms followed by death. Since the earliest descriptions of this ancient disease, animals, and especially dogs, have been recognized as the source and cause of rabies in humans (Rosset, 1985). To this day, rabies provides an exemplar of a One Health problem requiring an understanding of the linkages between human and animals and an integrated approach to disease control.

In 1882, shortly before discovering the first rabies vaccine for humans, aided by experiments on rabbits and dogs, Louis Pasteur wrote in his third correspondence to the Academy of Science: '[People contract rabies only after a bite of a rabid animal; it would be enough to find a proper method to fight rabies in the dog to protect humanity from this terrible scourge.]' (Pasteur *et al.*, n.d.).

Although this statement by Pasteur simplifies the epidemiology of rabies by ignoring sylvatic rabies in wildlife reservoirs and lyssavirus transmission by bats, it describes the very essence of prevention of rabies in humans. Even now, the domestic dog is the main vector for transmission of rabies to people, being responsible for more than nine out of ten cases worldwide. Over 15 million people/year come into contact with a rabid dog (Hampson *et al.*, 2015) and should receive post-exposure prophylaxis (PEP). This treatment is the only measure available to prevent onset of disease, but it is often inaccessible for various reasons, including lack of knowledge about where to seek help, lack of money to pay for it or simply lack of the vaccine itself in local health facilities.

Despite exploration of different protocols, no consistently effective treatment exists against rabies encephalitis and the disease is almost always fatal (Jackson, 2013). Although PEP is highly effective in terms of prevention, many hundreds of thousands of people across Africa and Asia do not have access to prompt appropriate PEP. As a result, it is estimated that at least 59,000 people die of rabies each year, which represents an under-reporting of human rabies cases by a factor of from 20 (Asia) to 160 (Africa) (Knobel *et al.*, 2005; Hampson *et al.*, 2015).

Rabies can also be effectively prevented in both human and animal hosts through pre-exposure vaccination, with several highly immunogenic and effective vaccines available. While large-scale vaccination campaigns in the animal host are cost-effective as a prevention tool for rabies in humans, pre-exposure prophylaxis (PreP) for human populations is not considered economically feasible nor sustainable as a control measure (Hampson *et al.*, 2018). The availability of effective vaccines raises

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the prospect for effective control and elimination of rabies, and several other features of rabies fulfil criteria for a disease that can be eliminated (Klepac *et al.*, 2013). The virus cannot persist in the environment, no carrier state has been identified, and the infectious period lasts only a few days before the host invariably dies (Warrell and Warrell, 2004). The basic reproductive ratio (R_0) of canine rabies transmission is consistently below 2, regardless of demographic setting or dog density (Hampson *et al.*, 2009; Morters *et al.*, 2013), which suggests that elimination should be epidemiologically feasible. This is supported by empirical evidence demonstrating the success of canine rabies elimination in Europe (Aikimbayev *et al.*, 2013), North America, and more recently in Latin America where human and dog rabies cases have declined considerably following dog mass vaccination campaigns (Vigilato *et al.*, 2013; Freire de Carvalho *et al.*, 2018). There is currently a global drive to eliminate canine-mediated human rabies by 2030, in line with the United Nations Sustainable Development Goals. In 2016, the Food and Agriculture Organization of the United Nations (FAO), the World Organisation for Animal Health (OIE), the World Health Organization (WHO) and the Global Alliance for Rabies Control (GARC) launched the initiative 'United Against Rabies' (UAR) (Lembo *et al.*, 2011; Minghui *et al.*, 2018), which currently leads global coordination for implementation of rabies control programmes. Beside the development of tools, guidelines and initiatives, several regional networks were established in dog-rabies endemic countries, serving as a platform for exchange among the partner countries. One example is the Pan-African Rabies Control Network (PARACON) founded in 2014. Its mission is to eliminate dog-mediated human rabies in sub-Saharan Africa by 2030 (Scott *et al.*, 2015). The main burden from this disease is still found in Asia and Africa, where rabies continues to be neglected in many regions, and too often its public health impact is overshadowed by other priority diseases such as HIV/AIDS, malaria and avian influenza (Knobel *et al.*, 2005; Shwiff *et al.*, 2013). This situation typifies the inequities in health investments, which are directed to prevention of emerging zoonoses (perceived as a threat to high-income countries) in comparison to prevention and control of neglected endemic zoonoses (predominantly affecting low-income communities) (De Balogh *et al.*, 2013; Zinsstag, 2013a). Although the number of lives lost and the estimated costs (Shwiff *et al.*, 2013) may be viewed as less compelling than other public health priorities, several studies have demonstrated the cost-effectiveness of canine rabies control for preventing human rabies deaths (Fitzpatrick *et al.*, 2014; Mindekem *et al.*, 2017). The threshold immunization coverage of the reservoir species required to interrupt transmission has been estimated at 70% (Coleman and Dye, 1996) as has been confirmed using a dog contact network model (Laager *et al.*, 2018). For canine rabies, vaccination campaigns have successfully achieved this level (Kayali *et al.*, 2003; Kaare *et al.*, 2009; Lechenne *et al.*, 2016; Sanchez-Soriano *et al.*, 2019), but challenges remain to reach and maintain sufficient coverage in highly dynamic and poorly supervised dog populations (Gsell *et al.*, 2012; Mauti *et al.*, 2017). Most importantly dog rabies mass vaccination must be coordinated at a regional level and natural barriers should be used to avoid reintroduction from non-vaccinated areas (Mauti *et al.*, 2019). Furthermore in some settings cultural barriers exist to dog vaccination and therefore the planning of vaccination campaigns needs to consider the local context to reach sufficient coverage (Muthiani *et al.*, 2015; Mosimann *et al.*, 2016). Awareness is also growing about the importance of ensuring completeness of vaccination campaigns among communities, to prevent gaps in coverage which severely jeopardize control efforts (Townsend *et al.*, 2013b). For human rabies prevention, poor access to pre- and post-exposure vaccines remains a problem in remote and marginalized communities (Warrell, 2003; Hampson *et al.*, 2011). Although the 2030 goal could be achieved with current availability of human rabies vaccine (Hampson *et al.*, 2019), the problems of delivery to people in need, appropriate health seeking by patients and compliance with immunization recommendations remain. A major challenge also relates to surveillance systems for both human and animal rabies, which are very poor or non-existent in many parts of Africa and Asia (Banyard *et al.*, 2013; Nel, 2013).

The described obstacles to rabies control can be addressed by an integrated approach based on the 'one medicine' concept, which is extended to One Health and even more broadly to systemic understanding of ecological (ecohealth) and social systems (health in social-ecological systems, HSES) (Zinsstag *et al.*, 2011). The resulting 'equity effectiveness' approach aims towards rabies control programmes that consider disadvantaged groups in order to reach the whole population equitably (Zinsstag *et al*., 2015a). Even when a vaccine is highly effective, as is the case with dog rabies vaccine, use in the field is often limited by a number of factors in a multiplicative way. As a result, the effectiveness of an intervention, assessed here as the proportion of dogs protected from transmission, may be well below the actual biological efficacy of the vaccine. A vaccine's intervention effectiveness is determined, among other factors, by availability, accessibility and affordability (Zinsstag *et al*., 2011; Muthiani *et al*., 2015; Mosimann *et al*., 2016). To better understand these determinants of intervention effectiveness we move from 'one medicine' to an HSES approach and discuss in detail their involvement in sustainable, cost-effective elimination of rabies in domestic animals.

One Medicine

More than a century ago, Austin Peters, a veterinarian and contemporary of Louis Pasteur, said the following before the Cattle Commission of the USA on the subject of combatting rabies:

> I merely offer the suggestion, would it not be better to merge matters pertaining to the public health in one bureau, this board not only to do what the present Cattle Commission does, but also to act in a broader scope, considering contagious animal diseases in their relation to the public health, as well as a menace to our live-stock interests. […] Before we can ever have a system of protection to the public health approaching perfection, it will be necessary to place the contagious and infectious diseases of animals in the same category with those of man, and have the same authorities exercise supervision over both.
>
> (Peters, 1891, p. 106)

Such a system would truly be preferable for the surveillance of rabies. Reliable incidence data on animal and human rabies, brought together in one shared database, would significantly enhance communication with decision makers on the different national and international levels, as well as with the public as a whole (Lembo *et al*., 2011; Banyard *et al*., 2013; Meslin and Briggs, 2013; Taylor and Partners for Rabies Prevention, 2013). In reality, even separate reliable rabies surveillance systems do not currently exist in either the veterinary or the public health sector. An online database created by the WHO, the Rabnet website, was discontinued due to inconsistent reporting and poor response (Nel, 2013). In many countries, rabies is not even included as a reportable disease (Nel, 2013). However, the recently established regional networks such as PARACON are clearly promoting a closer cooperation between the human and animal health sectors. An online African rabies epidemiological bulletin, which was launched in 2016 by PARACON, focuses in addition on capturing quality, timely pan-African data on human and animal rabies cases, vaccines administered, vaccination coverage and dog population estimates. This data will further be used for advocacy purposes for the control and elimination of canine-mediated human rabies (Scott *et al*., 2015). Currently there are not enough resources allocated to rabies surveillance and control. In consequence, only a small fraction of suspected animals are tested, compared with the number of humans receiving PEP (Townsend *et al*., 2013a). In Bhutan over 10,000 PEP treatments were reported between 2001 and 2008. In the same period just over 200 animals were tested by a laboratory (Tenzin *et al*., 2012), which means that the infectious status of the source was ascertained for less than 2% of all exposed cases. Neglect of rabies by the common disease reporting systems and lack of awareness in both the population and the service provider sector (Mbaipago *et al*., 2019) leads to extreme under-reporting of cases both in animals and humans and can also lead to misdiagnosis as another encephalitic infection, particularly malaria, in humans (Mallewa *et al*., 2007).

Good surveillance is not only an important prompt for the international community to recognize rabies as a public health tragedy but is also indispensable for control and especially elimination attempts (Klepac *et al*., 2013). Diagnostic capacity and surveillance are essential to promote vaccination campaigns and to demonstrate the effectiveness of interventions. During and after mass vaccination campaigns, surveillance sensitivity must increase considerably in order to continue detecting cases once they become rare (Klepac *et al*., 2013; Townsend *et al*., 2013a). Further genetic analysis of the rabies strains provides additional information about the main routes of viral dissemination, which can be consequently used in planning rabies control programmes. The case of N'Djamena, the capital of Chad, clearly demonstrated an interruption in canine rabies transmission after a citywide vaccination campaign with sufficient vaccination coverage. However, rabies reappeared and Zinsstag *et al*. (2017) hypothesized that reintroduction may have been due to introduction of rabid dogs from neighbouring areas.

Improvement of surveillance can be achieved by close communication between animal- and human-health workers (Meslin and Briggs, 2013). The advantages of sharing information are clear: (i) related to each human rabies case, there is an animal rabies case; and (ii) connected to each animal rabies case, there are possible human exposures. From information about incidence of bites to humans, the veterinary sector can draw conclusions about rabies incidence in animals. Conversely, starting from a known rabid animal, human exposure can be explored by a contact tracing approach (Diop *et al.*, 2007; Hampson *et al.*, 2009; Banyard *et al.*, 2013). Such a tracking method is in line with the concept of risk-based surveillance, which is economically advantageous for both sectors (Stark *et al.*, 2006). In Bohol in the Philippines, contact tracing has been successfully applied (Lapiz *et al.*, 2012).

Arguably the greatest advantage of close cooperation of human and animal health services is the avoidance of unnecessary, costly PEP delivery resulting from the unknown status of a biting animal and uncertainty about the epidemiological situation in an area. Examples of overuse of vaccine are frequent and are partly a direct consequence of poor cooperation but also a result of the understandable anxiety associated with consequences of mistakenly withholding PEP. In Bhutan, a whole region continued PEP treatment to bite-patients despite elimination of rabies from this particular district because in the southern part of the country frequent introduction of rabies from India still occurred. Due to these introductions, Bhutan did not acquire rabies-free status from the WHO (Tenzin *et al.*, 2011, 2012). Similarly in Tunisia, Thailand, Sri Lanka and Chad, the demand for PEP increased after dog vaccination campaigns, presumably due to increased awareness of rabies, but contrary to expectations (Mitmoonpitak *et al.*, 1998; Kumarapeli and Awerbuch-Friedlander, 2009; Touihri *et al.*, 2011; Mindekem *et al.*, 2017).

In India, Dr M.J. Mahendra described a phenomenon that grew among people with public awareness that he called the 'hydrophobia phobia', and Cleaveland *et al.* (2006) found that in Tanzania rabies was more feared than malaria, despite being less prevalent. In France, where the rabies-free status is repeatedly threatened by imported rabid dogs from endemic countries, media warnings on reintroduction increase the demand for PEP and rabies immunoglobulin (RIG) (Lardon *et al.*, 2010; Gautret *et al.*, 2011).

Wasting valuable products, which are indispensable in an actual exposure, can lead to shortages, as described in Europe and the USA (Bourhy *et al.*, 2009). In low-income countries, where post-exposure vaccines are rare and RIG is virtually non-existent, each injudiciously used dose can potentially result in a fatality for another exposed rabies victim. Uncertainty about the exposure status of a victim could in many cases be avoided through an integrated 'one medicine' thinking and close collaboration between physicians and veterinarians. Veterinary services can observe and follow up animals that inflict a bite for 10 days. If the animal is still alive after that period of time, there is no risk of rabies and PEP for the respective victim can be discontinued. This approach is known as Integrated Bite Case Management (Undurraga *et al.*, 2017).

To prevent unnecessary, expensive PEP after bites from negative animals or undetected exposures from a truly rabid case, each human presenting at any health facility for the treatment of a bite wound should trigger a contact to the veterinary service to notify the case. Thus, information on vaccination status of the animal and the result of diagnostic tests, if performed, can be shared, and an investigation on the occurrence of other exposures (human or animal) or additional cases in the same area can jointly be undertaken.

Ideally, as suggested by Peters in 1891, a One Health rabies surveillance system should automatically involve such direct communication between public and animal health sectors and involve well-trained specialized personnel who are able to engage in timely dog rabies diagnosis and human PEP. Even if human and animal health facilities remain separated, scarce infrastructure and equipment, such as microscopes and refrigerators, as well as resources such as electricity, could potentially be shared for rabies surveillance and control (Schelling *et al.*, 2005). Savings from such sharing of resources in developing countries should not be underestimated, as the most basic infrastructure can be hard to find, especially for public institutions.

A recent study in Tanzania showed that even if only 1% of all PEP administered was given to people truly exposed, it remains cost-effective (Hampson *et al.*, 2011). However, concentrating on human PEP will never interrupt transmission. Ultimately, only an intervention in the reservoir host can lead to dog rabies elimination, and this approach will be more cost-effective than human PEP (Zinsstag *et al.*, 2015b). The next step to sustainable control should be a joint effort of veterinary and human medicine, enhancing intersectoral communication and controlling rabies at its animal source.

One Health

While 'one medicine' has a clinical and curative connotation, the term One Health emphasizes the added value of preventive action from closer cooperation between public and animal health (Zinsstag *et al.*, 2015a,b). In low-income countries, the 70% threshold of coverage to interrupt transmission can often only be achieved by providing the vaccine free of charge (Durr *et al.*, 2008, 2009). It is usually recommended that freedom from dog rabies is considered a public good, and that in low-income settings, dog rabies vaccination should be free of charge to the owner. Comparative cost-effectiveness analyses of dog mass vaccination compared to human PEP alone informs authorities and decision makers considering whether to engage in dog rabies mass vaccination. While government veterinary services remain committed to mechanisms for cost recovery, it is unlikely that any fees recoverable during a mass dog vaccination campaign would offset the additional costs involved (i.e. an extra person involved in handling cash during vaccination campaigns). There are many reasons why charging a fee at the point of vaccine delivery could be counter productive, for example, if vaccine is refused to dogs brought by children who are without the means to pay for vaccination. None the less, other mechanisms may exist for supporting dog vaccination campaigns through owner payments, for example, through charging dog registration fees, as has been introduced successfully in the Philippines, or through establishing community insurance schemes.

The WHO promotes mass canine vaccination as part of a cost-effective approach to human rabies prevention and estimates that in areas where the dog population is the only driver of epidemiology, this approach becomes more cost-effective than PEP alone after a period of 15 years (Bogel and Meslin, 1990). Many successful dog vaccination campaigns have been undertaken in the last few decades, which led to the control of rabies and marked declines of human rabies in Latin America and several regional settings in Africa and Asia (Belotto *et al.*, 2005; Lucas *et al.*, 2008; Davlin and Vonville, 2012). The cost-effectiveness of such campaigns has occasionally been assessed (Cleaveland *et al.*, 2006; Zinsstag *et al.*, 2009; Tenzin *et al.*, 2012). In N'Djamena, Chad, the cost of dog vaccination compared to PEP alone breaks even after 10 years, provided there is no reintroduction after the successful elimination occurs (Mindekem *et al.*, 2017). Figure 19.1 shows the cumulative cost of human PEP if there is no communication between public health and animal health as being the highest, when compared to the cumulative cost of dog mass vaccination with PEP with optimal communication between public and animal health. An equal time period to achieve similar cost-effectiveness has been reported for vaccination campaigns in Bhutan (Tenzin *et al.*, 2012).

This clear advantage of canine vaccination is due to the very high costs of human PEP vaccine and immunoglobulin. Vaccinated, rabies-free domestic dog populations can considerably lower the demand for PEP, but as discussed in the previous section, this does not always occur. Figure 19.2 shows a projection of possible worst and best case scenarios for progression of PEP demand after a vaccination campaign. The rise of awareness for rabies in the course of interventions is closely linked to a rise in PEP numbers. Closer contact between veterinary and human medicine can buffer this impact. In parallel, studies to find new, less expensive vaccines and regimens demanding smaller and less frequent vaccine doses, like the recent WHO-accepted intradermal administration, must be maintained to constantly improve cost-effectiveness of PEP itself (WHO, 2018).

If one area has successfully eradicated rabies, there will always be a danger of reintroduction as long as the disease persists in other regions. Documented examples of constant rabies introduction pressure exist for the cities of Bangui (Bourhy *et al.*, 2016) and N'Djamena (Zinsstag *et al.*, 2017). Even if natural barriers block free movement of dogs, human behaviour can transmit the disease over long distances (Talbi *et al.*, 2010). In the same speech cited above, Austin Peters also pointed out the necessity for the local authorities to enforce the law and supress outbreaks of the disease, but regretted that neighbouring authorities do not cooperate well enough:

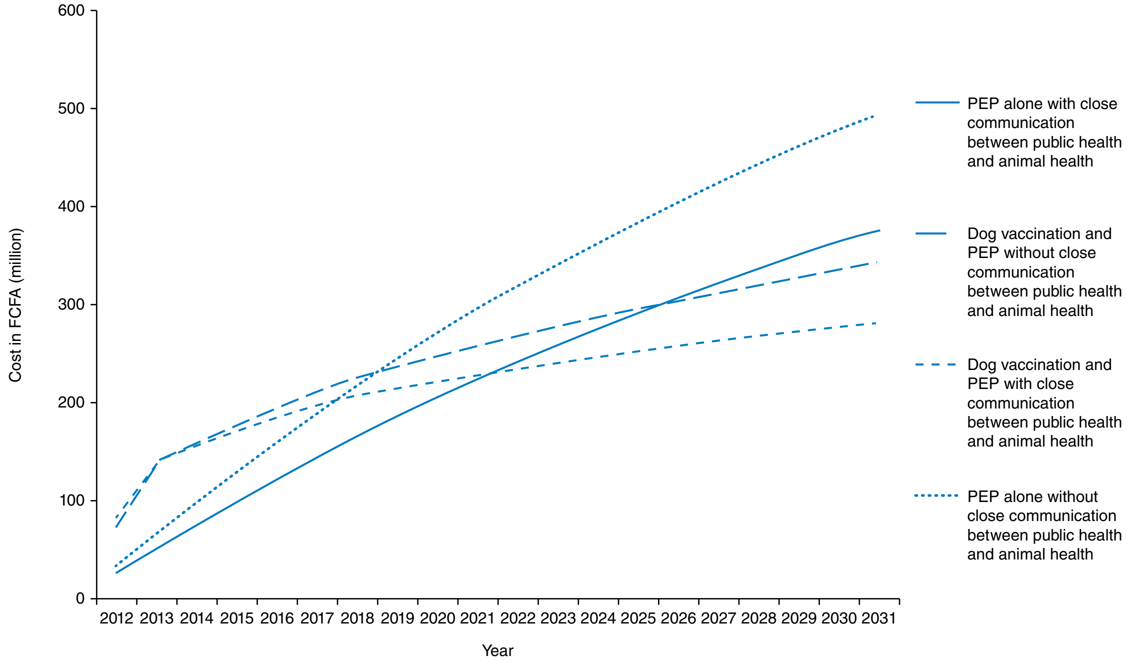

Fig. 19.1. Comparative cumulative cost of rabies control using post-exposure prophylaxis (PEP) and dog mass vaccination, with and without communication between public and animal health sectors. Adapted from Mindekem *et al*., 2017.

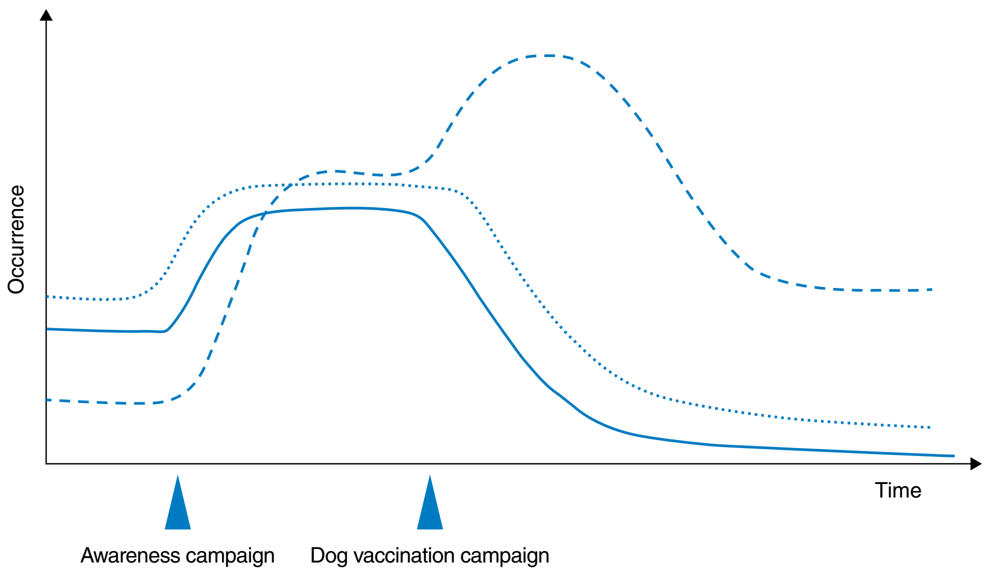

Fig. 19.2. Scenarios for the influence of dog vaccination campaigns on the demand for human PEP: trend of rabies incidence (continuous line); possible rise in PEP due to elevated rabies awareness (broken line) and the preferred decline of PEP following the decrease of rabies risk (dotted line).

> Last summer the town of Framingham ordered that all dogs within its limits must be muzzled. Now the town of Brookline orders all dogs muzzled or chained for sixty days, while most of our cities and towns take no action whatever in regard to the matter; but it is very doubtful if such erratic and independent action has any marked influence upon the prevalence of the disease.
>
> (Peters, 1891, p. 105)

For successful elimination of rabies, concerted joint measures and common efforts are needed across many different administrative zones within a country, and even between countries. Figure 19.3 illustrates a provisional proposal for a coordinated approach for dog rabies elimination in Africa, using the geographical barriers of the Sahara Desert and the oceans. For example, the mass vaccination of dogs in West and Central Africa should start in Mauritania and move in a coordinated fashion towards the East and South (Mauti *et al.*, 2019). Unfortunately, dogs fall into an administrative gap in developing countries. The veterinary sector is focused on livestock health and companion animals are ignored because they lack value for the economy, whereas most public health ministries will only deal with human aspects, rarely being motivated (or trained) to tackle problems in other species (Mbilo *et al.*, 2018).

Meanwhile, a simple calculation illustrates financial advantages for actions at the source of rabies transmission. If an unvaccinated dog contracts rabies and bites two people, these two victims each have to take three to five doses, depending on the post-exposure regimen applied. If treatment is not sought, not available or improperly administered, each victim faces a 20% probability of death from rabies (Shim *et al.*, 2009). As a practical example, reflecting the analysis presented in Fig. 19.1, dog owners in N'Djamena are shown the advantage of vaccination with the help of very clear figures: it is their choice to spend the equivalent of US$5 (cost for vaccination by private veterinary sector) for dog vaccination now, to spend US$100 per victim in the event that their dog becomes rabid and bites, or to face the consequences of a human death when no PEP is administered. What is evident in this micro-relationship from

Fig. 19.3. Scenario of a possible spatio-temporal coordinated dynamic of dog rabies elimination in Africa (Mauti *et al*. 2019, reprinted with permission).

case to case also holds as a broad picture for the macro-level of rabies economics. If money is not allocated to prevention at the source of infection, the spending that occurs farther on for PEP treatment of all possible victims to prevent human rabies is considerably higher, as illustrated in Fig. 19.4. Ultimately, the loss of lives, if sufficient resources for good access to PEP are lacking, will cost the economy of a country 100 times more than an investment in dog vaccination. Millions of dollars are therefore lost worldwide. Expressed in disability adjusted life years (DALYs), rabies accounts for over 3.7 million life years lost, a figure that considers the number of deaths but also the fact that most victims are children, resulting in lost potential of tens of thousands of productive years (Hampson *et al.*, 2015).

A substantial part of the economic burden to a country can also be livestock losses due to rabies, especially in Asia where the highest numbers are reported (Shwiff *et al.*, 2013). The cost of rabies to the cattle production in Ethiopia is estimated at over US$100 million, although this study uses only data on rabies-suspected dogs, which were not confirmed by standard diagnostic tests. This cost, when used for dog rabies mass vaccination would allow cover for the whole country (Jibat *et al.*, 2016). This provides an additional incentive to take action against dog rabies. In some areas (e.g. Botswana) cattle are the species for which most rabies cases are reported. Because they are kept on farms far from settled areas, it is suspected that jackals rather than dogs could be the vector for rabies transmission to livestock (Moagabo *et al.*, 2010). Such additional disease reservoirs might only become apparent during the last phase of disease elimination (Klepac *et al.*, 2013). Others are already identified and may undermine attempts to control rabies by repeatedly reinfecting previously rabies-free domestic populations. The ecological perspective of

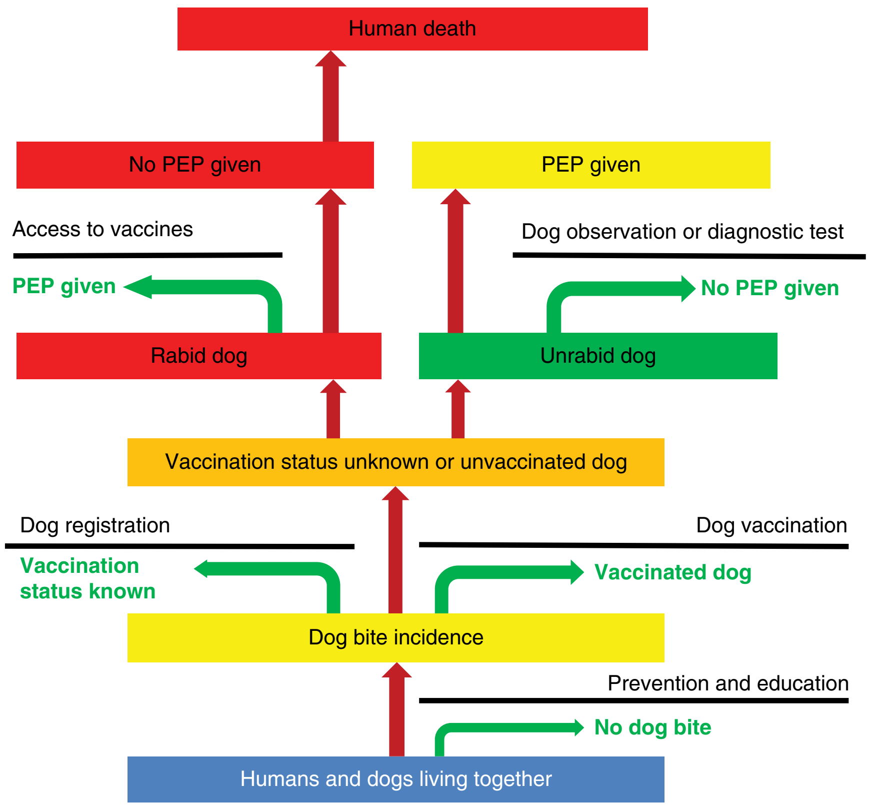

Fig. 19.4. Possible progress from a dog bite to PEP or human death. Black bars show intervention possibilities to prevent further economical impact and harm, green arrows point to the positive effect of the intervention, red arrows point to further step of aggravation of the situation.

rabies control and the problem of complex epidemiological settings for the elimination of rabies will be discussed in the next section.

Ecosystem Approaches to Health

One Health focuses on the closer cooperation of human and animal health. As such it is embedded in the broader concept of ecosystem approaches to health (Zinsstag *et al*., 2012). Because in the Americas the majority of domestic animals are vaccinated, bats became apparent as the second most important source of rabies in humans (Belotto *et al*., 2005). Particularly in the USA, where rabies has been eliminated in domestic animals, the epidemiology has shifted to wildlife species like foxes, raccoons and skunks (Rupprecht *et al*., 1995). A very valuable source of information to establish the background relationships in rabies epidemiology in a given region is the molecular study of identified viral strains. This method has shown that mongoose rabies in Southern Africa forms an independent cycle (Nel *et al*., 2005). The same reservoir function is being disputed for the bat-eared fox (Nel, 1993; Sabeta *et al*., 2007). These examples show that in certain environments, control of rabies through dog vaccination should be complemented by rabies control in wildlife reservoirs (Muller *et al*., 2012). Close communication among biologists and wildlife veterinarians is required to detect these changes and patterns.

As rabies inevitably leads to death, outbreaks of the disease in small, vulnerable species populations can potentially lead to extinction. In the 1980s, domestic dogs were most probably responsible for an outbreak of rabies in the African wild dog (*Lycaon pictus*) (Gascoyne *et al*., 1993), which is listed as an endangered species. Domestic dogs are also blamed for repeated outbreaks of rabies in the Ethiopian wolf (*Canis simensis*) (Mebatsion *et al*., 1992), a distinct canid species endemic only to the Ethiopian Highlands. These examples show how rabies and other diseases transmitted from an abundant vector species like the domestic dog can have devastating impacts on small, endangered populations. This kind of local or worldwide extinction is not only an irrevocable loss for biodiversity, but often also results in a downgrading of affected national parks and conservation areas (Cumming and Cumming, 2015; Cumming *et al*., 2015).

An example where the epidemiology of rabies is driven by a domestic reservoir is the Serengeti and Ngorongoro region (Lembo *et al*., 2008), where dog vaccination is of great value to wildlife and ecosystems. Mass dog vaccination campaigns conducted in a 'clean corridor' around the Serengeti National Park (Kaare *et al*., 2009) resulted in elimination of canine rabies from pastoral and wildlife-protected areas of the ecosystem, despite the presence of abundant and diverse wildlife populations (Lembo *et al*., 2010).

Health in Social-ecological Systems (HSES)

Finally, the One Health idea can be extended to systemic approaches of health and well-being known as HSES (Zinsstag *et al*., 2011). In complement to ecological determinants, systemic social determinants are emphasized, such as the functioning of health systems and, arguably the most important actor in the fight against rabies, dog owners. In addition to affordability, other critical determinants of a successful dog vaccination campaign must be considered: accessibility, adequacy, acceptability and adherence. These factors are related in a multiplicative way and depend on the social and cultural context (Muthiani *et al*., 2015; Mosimann *et al*., 2016). Lack of understanding of these effectiveness factors prevents mass vaccination campaigns from reaching sufficient coverage (Matter *et al*., 2000; Kaare *et al*., 2009; Thomas *et al*., 2013). Even when vaccination teams work well and logistics are guaranteed, if there is low accessibility to vaccination posts or facilities, performance will be low. Polo *et al*. (2013) defines accessibility in this context as the sum of: (i) supply (vaccination sites); (ii) demand (dog densities); (iii) geographical barriers between supply and demand; and (iv) people's awareness of the benefit. The first three points are closely linked: the locations of vaccination points should be carefully chosen based on dog density, as determined by prior dog demographic studies, or as estimated on the basis of human density and dog to human ratio as well as geographical distances and barriers. In special cases where there are only a few, small, far apart settlements or where mobile populations are involved, mobile vaccination teams might be a better option than poorly performing fixed posts (Kaare *et al*., 2009).

Stakeholders, including dog owners, municipal authorities, and community health and veterinary workers, should be involved in planning interventions from the beginning. Community ownership and participation are part of a transdisciplinary approach (Matter *et al.*, 2000; Catley and Leyland, 2001; Lapiz *et al.*, 2012; Schelling and Zinsstag, 2015). In Grenada, willingness to bring a dog to vaccination facilities was low, because people feared that their animal might be infected by ectoparasites from other animals (Thomas *et al.*, 2013). In such cases, rabies vaccination could be combined with a treatment against parasites or hygiene measures to increase the perceived benefits of participation (Catley and Leyland, 2001; Kaare *et al.*, 2009; Thomas *et al.*, 2013). Another cause for low participation can be misconception about the vaccine itself (Belsare and Gompper, 2013). For instance, fear that it might cause rabies, render the dog too friendly to be a good guardian or that the vaccine is a poison (Monique Léchenne, personal observation, Chad). A recent dog mass vaccination campaign in N'Djamena showed that dog owner participation markedly affects cost per vaccinated dog. The cost per vaccinated dog varied between US$0.6 and US$130 per dog, depending on whether 300 dogs or only one were vaccinated per day.

A further aspect of effectiveness is ability to handle the dogs (Fig. 19.5). The human–dog relationship is determined by socio-cultural factors, with differences in the tameness of dogs observed between different religious backgrounds in Chad and in Tanzania; dogs in predominantly Muslim communities were more difficult to handle than those in others (Cleaveland *et al.*, 2003), whereas in a Buddhist setting, it may even be possible to handle stray dogs (Bogel and Joshi, 1990). In certain contexts, dogs in wealthy households are more likely to be vaccinated (Awoyomi *et al.*, 2008). However, in other settings poor communities were found to be more accessible to dog mass vaccination, provided it was free of charge (Lechenne *et al.*, 2016). Consideration of social and ecological determinants provides the key for locally adapted and effective approaches towards dog rabies elimination in a given context. Such systemic approaches contribute to a science of dog rabies elimination (Zinsstag, 2013b).

Cultural practices and low income may lead to poor supervision of dogs in developing countries. The majority of people in Africa, for example, do not allocate family resources for their dogs. Dogs are fed with leftovers from the table and left to forage when the quantity is insufficient. In addition,

Fig. 19.5. Differences in willingness of dogs to be handled, illustrated by a compliant dog (A) and a difficult dog (B), wrapped in a mosquito net and transported by wheelbarrow. Photos courtesy of Monique Léchenne.

dwellings in resource-poor settings are often not fenced. A false conclusion is often drawn that the majority of dogs roaming in the street are ownerless in low-income countries. This false supposition is then followed by another wrong conclusion that getting rid of these ownerless dogs equals getting rid of rabies. Despite substantial scientific evidence against the culling of dogs as a control for rabies (Windiyaningsih *et al*., 2004; Morters *et al*., 2013; Putra *et al*., 2013), the practice continues. There are several reasons for failure of this method. For instance, due to fear of culling people may relocate dogs to an area where rabies is not currently prevalent or may seek a replacement dog from a rabies-prevalent area and reintroduce the disease (Davlin and Vonville, 2012). But one of the most important undesirable effects of culling interventions is that the fight against rabies is negatively perceived in society and results in lack of community support.

To confront the problems of low awareness, low motivation and low possibility of handling dogs, participatory community engagement, information, education and communication are central elements of successful rabies control. Education can help to prevent dog bites and human rabies exposure.

Children are the most vulnerable group for exposure and can be taught at an early age how to behave to avoid conflicts with animals (Mitmoonpitak *et al*., 2000; Kilic *et al*., 2006). In the Philippines, the rabies child education intervention has been extended from Bohol Province to other endemic areas, like Palawan Province (Deray *et al*., 2018). This entailed adaptation of the rabies curriculum teachers' manual that was institutionalized through passing a local government resolution. This allowed government funds and staff to be used in implementing integration of rabies and responsible pet ownership in the elementary school curriculum. Actual implementation was achieved by the teachers and local officials of the Department of Education. Training and orientation sessions were conducted for school superintendents, school nurses, head teachers and Rural Health Unit (RHU) midwives. This was patterned after successful adaptation of the national prototype by the Bohol provincial rabies education programme, where teaching modules on rabies were incorporated into diverse subjects, including mathematics, science, health, social science, English and Filipino (Lapiz *et al*., 2012).

The key to this successful assimilation was involvement and ownership of the educators and local government officials from the Department of Education and their work in adapting the national prototype teacher's manual on rabies curriculum integration. Public consultations with educators, intensive planning and workshops to develop lesson plans, and orientation and training of teachers who would use the tool were conducted (Lapiz *et al*., 2012). To complement this effort was the creation of Rabies Scouts, who completed a rabies and responsible pet ownership training programme. They served as examples of positive action for other children. A major endeavour during celebration of the National and World Rabies Days are fun educational events for children, such as poster-making contests and pet shows to celebrate the bond between children and pets. The main programme limitation is that the intervention only reaches children enrolled in schools, failing to include those who are likely to be at higher risk of being exposed to rabid dogs. Rabies prevention education for children who are not enrolled in formal educational programmes should not be neglected and should be included in community education strategies. This education component of a comprehensive One Health approach is important for the long-term sustainability of the programme, since the children continue to have higher awareness and are a source of accurate information about the disease, its prevention and responsible pet ownership.

Conclusion

Integrated approaches to rabies control based on One Health thinking have clear advantages towards elimination of dog rabies. For example, integrated surveillance of dog rabies and human exposure by closer cooperation between public and animal health increases the sensitivity of surveillance and should avoid unnecessary or overuse of PEP. One Health approaches further provide evidence for:

1. The feasibility of elimination of dog rabies by mass vaccination at high coverage, which cannot be achieved by dog culling or prevention in humans alone.
2. A higher cost-effectiveness of dog mass vaccination and PEP versus PEP alone, after 5–15 years, with interruption of dog rabies transmission.
3. The importance of understanding rabies ecology, and community engagement, for development of locally effective and equitable dog mass vaccination campaigns.

To reach the goal of rabies elimination by 2030, set by the WHO and partners (WHO, 2015), we will have to reach further than veterinary and human medicine and also include biologists, cultural scientists, sociologists and geographers. Some say the goal of elimination is a far reach, but more than 100 years ago in his letter to the Academy of Science, Pasteur continued regarding rabies control: 'This goal is still far away, but in light of the facts that precede, is it not permitted to hope that the efforts of modern science will achieve it one day?' (Pasteur *et al*., n.d.).

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20 Brucellosis Surveillance and Control: a Case for One Health

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Introduction

Brucellosis, a bacterial disease causing abortion in livestock and chronic illness in humans, is endemic in both extensive and intensive livestock systems throughout Asia, Latin America and Africa and some European countries (Dean *et al*., 2012b). As it is one of the most geographically widespread zoonoses in the world (Pappas *et al*., 2006; Dean *et al*., 2012b) causing disease in both livestock and people while evolving epidemiologically, brucellosis illustrates well the importance of a One Health approach for disease prevention and control, by demonstrating added value from closer cooperation of the human and animal health sectors at different levels.

Despite increasing evidence on the effectiveness of One Health approaches in the surveillance and control of zoonoses, institutional barriers continue to limit cooperation. Humans are exposed through direct contact with infected animals or the consumption of unpasteurized milk or dairy products. Most of the published research focuses solely on either human or livestock brucellosis, although recent studies more often recommend a One Health approach for more effective control, including the involvement of the social sciences (Marcotty *et al*., 2009). Endemic zoonoses remain neglected because their overall impact and beneficial use of synergies between sectors are rarely evaluated.

The impact of zoonoses is usually assessed separately in different sectors such as public health, livestock production and households. Consequently, costs and benefits of control are not considered for society but rather separately within these systems. The quantifiable proportions of brucellosis underreporting are poorly documented. Brucellosis belongs to the neglected zoonotic diseases (WHO/DFID-AHP, FAO and OIE, 2006) and is regarded as a foodborne disease (WHO, 2015), but is not grouped with the neglected tropical diseases that receive more international attention (WHO, 2020).

The most important preferential reservoir host for *Brucella abortus* is cattle, while for *Brucella melitensis* it is sheep and goats, and for *Brucella suis* it is pigs. *B. abortus* and *B. melitensis* cause important productivity losses in livestock. Although *Brucella* species differ widely in host preference, phenotypic characteristics and pathogenicity, they are genetically homogeneous, with more than 99% nucleotide sequence identity as demonstrated by comparative whole genome analysis (Scholz and Vergnaud, 2013). In the past two decades, shifts in epidemiology are seen, for example, with *B. melitensis* infections

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in cattle (Godfroid *et al*., 2014). *B. abortus* and *B. melitensis* can spill over into other livestock populations such as yaks and camels (Bayasgalan *et al*., 2018), and *Brucella* spp. also spill over from livestock to wildlife. Cases of documented *Brucella* spp. being maintained in wildlife are so far limited: (i) *B. abortus* in North America (bison and elk) and Africa (African buffalo); (ii) *B. melitensis* (ibex) in France (Mick *et al*., 2014); and (iii) *B. suis* (wild boar) in Europe. Opportunities where livestock transfers brucellosis to wildlife should be reduced, both for conservation issues and to decrease the risk of reintroduction after previous elimination in livestock, with subsequently more human cases than from direct exposure to wildlife (Godfroid *et al*., 2013b).

Very few countries are free of 'ruminant brucellosis' (caused by *B. melitensis* and *B. abortus*) and even fewer are free of zoonotic brucellosis (OIE, 2008). However, there are many countries with no laboratory records on brucellosis (Pappas *et al*., 2006). Research studies in such 'white spots' commonly find brucellosis in both people and livestock (e.g. Côte d'Ivoire, Kanoute *et al*., 2017), sometimes noting important seroprevalences. Representative data on human brucellosis is even rarer (Dean *et al*., 2012b). Given the re-emergence of human brucellosis in some regions, particularly in the countries of the former Soviet Union and in China (cited in Zheng *et al*., 2018), and the prevailing endemic situation, which is not well described in many resource-poor countries (Ducrotoy *et al*., 2014), planning of control measures must go beyond classical textbook approaches.

The aim of this chapter is not to reiterate the biological characteristics and clinical understanding of brucellosis. We focus on *B. meilitensis* and *B. abortus*, despite that more interdisciplinary and intersectoral studies on *B. suis* are also warranted; however, we summarize briefly key features of zoonotic brucellosis in Box 20.1. In this chapter, we concentrate on how a One Health approach to brucellosis for epidemiological assessments, surveillance and laboratory capacity, cross-sector economics and practical control options, provides more insight when compared with human health or veterinary studies alone. Most of the examples are from Central Asia and Sahelian Africa, areas with either known high human incidences or only little information on the status of brucellosis occurrence in people and animals.

Box 20.1. Zoonotic brucellosis.

Human infection results mainly from direct contact with infected animals (often occupational exposure) or by consumption of contaminated raw milk or dairy products (consumer exposure). The most important causative agents are *B. melitensis* (sheep and goats), *B. abortus* (cattle), *B. suis* (pigs) and *Brucella canis* (dogs).

Brucella are Gram-negative coccobacillary bacteria with an intracellular predilection in the host. The main clinical feature in livestock is late-stage abortion, when bacteria are excreted in high numbers. Organisms are also excreted in semen and uterine discharge and may be shed for prolonged periods in milk after cessation of clinical signs. Brucellosis mainly causes loss of fertility (poor reproductive performance due to abortion, retained placenta and weak offspring) and subsequent reduction of milk production in sheep, goats and cattle.

Symptoms of the disease in people are highly variable. Generally, *B. melitensis* causes more severe illness, while *B. suis* and *B. abortus* cause less severe forms. The main symptoms are fever, sweats, malaise, anorexia, headache, arthralgia, myalgia, back ache and weight loss. The bacteria can localize anywhere in the body. Localization of the organism in bones and joints is common, with more than half of patients experiencing joint and/or back pain, due to arthritis, spondylitis and sacroilitis. Two-thirds of cases become chronic, and illness may continue for years when patients do not receive appropriate treatment. Severe outcomes of untreated cases are not rare, with neurological events occurring in four out of 100 cases and endocarditis in one in 100 cases (Dean *et al*., 2012a).

Human-to-human transmission of brucellosis is very rare. Uncomplicated acute human brucellosis is treated with doxycycline-streptomycin or doxycycline-gentamicin combination therapy. Focal forms often require prolonged treatment.

Human brucellosis can only be prevented by elimination in animals. Control and elimination in the animal host is most effectively achieved by mass vaccination and, if possible, subsequent test-and-slaughter programmes (Zinsstag *et al*., 2011).

Joint Surveys and Surveillance of Brucellosis in Humans and Livestock

To understand the transmission of brucellosis from livestock to people, simultaneous investigation in humans and animals is required. These studies may reveal an epidemiological linkage to the main animal source (livestock species) of infection, the level of under-reporting of cases or serve as the basis for animal–human transmission models. Such results can hardly be obtained from studies in animals or humans alone (Schelling and Hattendorf, Chapter 8, this volume). For brucellosis, the role of laboratories cannot be underestimated.

A significant human–animal linkage in cross-sectional studies is more likely to be detected at a higher spatial resolution (e.g. national and provincial level) than in a smaller geographical area (e.g. household, district or village level) when looking at past exposure using serology results (acknowledging its intrinsic diagnostic test characteristics). This is likely because of different life spans of people and livestock and seasonal separation of people and livestock notably in mobile livestock production systems, leading to non-uniform distribution of disease frequency and spatial heterogeneities. In a large representative cross-sectional study in cattle, sheep, goats and humans in Kyrgyzstan, human seroprevalence was associated with seroprevalence in sheep at the district level (Bonfoh *et al*., 2012). The important role of sheep in the transmission dynamics of brucellosis in Kyrgyzstan was further substantiated by isolation and characterization of *B. melitensis* in both sheep and cattle samples. No human brucellosis strains from Kyrgyzstan have been characterized to ascertain the animal source (Kasymbekov *et al*., 2013).

A combination of serological and bacteriological studies in animals and humans proves to be a powerful tool to characterize transmission of brucellosis from various livestock reservoirs to people and within livestock (Godfroid *et al*., 2013a). In a joint epidemiological study of human and animal brucellosis in Togo, livestock seropositivity was restricted to cattle only, with no seropositive small ruminants. *B. abortus* was isolated from cattle joint hygromas. Brucellosis did not appear to be a human health problem in the study zone despite the evidence of exposure in the cattle population. It may be possible that the Togolese *B. abortus* strain has a low potential for transmission or a lower pathogenic potential in humans (Dean *et al*., 2013). The isolated *B. abortus* strains from cattle harboured a large deletion in a gene *BruAb2_0168*. This gene is of particular interest because it is used as a polymerase chain reaction (PCR) target to identify the species *B. abortus* and it encodes a putative autotransporter which might be involved in virulence and/or host predilection (Dean *et al*., 2014).

Human incidences can be estimated from seroprevalence data (Box 20.2), while noting the sensitivity and specificity of serological tests and that serology does not differentiate between *Brucella* strains. Still, such estimates provide more information on under-reporting when compared with national incidence statistics. Given an apparent human seroprevalence of 8.8%, as determined by a serological survey conducted in Kyrgyzstan, the incidence of brucellosis exposure was estimated, with the method described in Box 20.2, to be 880 (95% confidence interval (CI) 400–1770) persons per 100,000/year. The estimated human incidence in 2007 was found to be more than ten times higher than the annual incidence of the reported clinical brucellosis cases (Bonfoh *et al*., 2012). A burden of disease study used data of 2013 (1 year after introduction of small ruminant vaccination in Kyrgyzstan). The available data was corrected for underestimation of reported cases. The authors estimated twofold under-reporting when compared with official numbers (Counotte *et al*., 2016).

Stratification of livestock seroprevalence by the age of the animal allows the estimation of the basic reproductive ratio (R_0), which is the number of secondary infections that one infectious individual may induce in a naive population. R_0 is necessary to estimate the needed effective immunization level to interrupt transmission of a disease (Box 20.3).

Surveys are commonly done in communities with expected high risk of exposure (e.g. in livestock-keeping communities) and are not necessarily representative for the national population. Consumers of livestock products, notably of raw milk products or undercooked meat in urban centres, are not included. To work towards estimation of national and global burdens and for advocacy on control of neglected zoonoses, more national burden of disease estimates would allow better comparison to prioritized health issues, but survey data from all population strata are necessary.

The consequences of a more comprehensive surveillance approach are far reaching since surveillance provides a picture of changes over time and achieved outcomes of interventions and can identify gaps such as capacity needs in laboratories and

Box 20.2. Estimating incidence of clinical brucellosis from seroprevalence data.

A study of human and animal brucellosis seroprevalence in Mongolia found a high human seroprevalence (17%) among rural populations likely to be exposed to brucellosis, suggesting significant under-reporting. Among seropositive people, 58.5% had at least two symptoms and 31.5% had at least three symptoms, indicating active clinical brucellosis (Tsend *et al*., 2014). A catalytic model was used to estimate human clinical brucellosis incidence from seroprevalence data, assuming that brucellosis antibodies would be detectable for 10.9 years after exposure (Eqns 20.1–20.3). In endemic stable transmission, Eqns 20.1 and 20.2, the change in the number of susceptible and infected individuals over time, respectively, can be set to zero. The seroprevalence $P = I/(S + I)$ (where I and S are the numbers of infected and susceptible people, respectively) is then equal to $a/(a + b)$, where a is the incidence of exposure and b is the immunity loss rate. Solving for a returns the incidence of exposure, of which 10–50% of new human cases may have clinical symptoms (Tsend *et al*., 2014). The model cannot distinguish between acute and chronic cases or relapses.

$$\frac{\partial S}{\partial t} = -aS + bI \qquad (20.1)$$

$$\frac{\partial I}{\partial t} = aS - bI \qquad (20.2)$$

$$P = \frac{a}{(a+b)} \qquad (20.3)$$

Where:
S = number of susceptible people
t = time
I = number of infected people
P = seroprevalence
a = incidence of exposure
b = immunity loss rate

Box 20.3. Calculating R_0 from age prevalence data of livestock.

The basic reproductive ratio (R_0) of a disease is the number of secondary cases generated from one infectious case in a susceptible population at the onset of transmission, thereby giving an indication of the ability of the disease to spread within a population. Age prevalence data was used to estimate the basic reproductive ratio in sheep (R_0 = 1.03), goats (1.02) (*B. melitensis*) and cattle (1.09) (*B. abortus*), using the likelihood function for R_0 related to the age distribution of seropositive and seronegative animals (Eqn 20.4) (Baljinnyam, 2014), whereby μ is the average age and a and b are the respective ages of seropositive and seronegative animals at the time of sampling. Given that the estimated R_0 values for each species are close to 1, this indicates low-level endemic stable transmission of brucellosis in extensive pastoralist settings of Mongolia (Keeling and Rohani, 2007).

$$\text{Likelihood } R_0 = \prod_{a=1}^{n} e^{(-a_\mu(R_0-1))} \prod_{b=1}^{n} (1 - e^{(-b_\mu(R_0-1))} \qquad (20.4)$$

The values of R_0 calculated based on age prevalence data are lower than the effective R_e estimated from a transmission model where R_e = 1.2 and 1.7 for sheep and cattle, respectively (see below). The effective reproductive number R_e represents the number of secondary infections during ongoing transmission (i.e. a non-naive population). With regard to use of R_0 to calculate the minimum needed immunization coverage to interrupt transmission, it is appropriate to use the higher estimates of R_e = 1.2 and 1.7. Assuming more conservatively R_0 = 2, a minimum threshold vaccination coverage p_c of 80% is proposed for the Mongolian livestock population. The threshold vaccination coverage p_c indicates the proportion of animals (sheep, goats and cattle) that should be immunized to interrupt transmission, calculated using Eqn 20.5. The term v is the efficacy of the vaccines (Rev.1 and S19) in reducing transmission, which is assumed conservatively to be 65% including an assumed loss of efficacy from disruptions in the cold chain. More epidemiological research is needed to estimate the R_0 and p_c of brucellosis in other contexts.

$$p_c = \frac{\left(1 - \frac{1}{R_0}\right)}{v} \qquad (20.5)$$

patient care. Joint human and animal surveillance can be active (e.g. repeated cross-sectional studies described above) or passive, with recording of cases in humans and animals (though with unknown sensitivity and specificity of representation of the populations). The latter can be done in the respective concerned sectors, while ensuring timely communication, within and across sectors, and joint analysis and interpretation of results as well as shared planning of activities and contingency plans. Integrated human and animal health surveillance systems are expected to detect new disease foci earlier and be able to react faster to changing epidemiology of a zoonosis (Schelling and Hattendorf, Chapter 8 and Aenishaenslin *et al.*, Chapter 9, this volume). There are generic textbook chapters describing steps and operations for joint surveillance systems, including for brucellosis (FAO, 2003), but more results on how to sustainably operationalize integrated human and animal systems is required (Aenishaenslin *et al.*, Chapter 9, this volume). As both human and animal health surveillance systems move information from district to provincial to national levels, for zoonoses it would be important that the data is crosschecked between sectors at each level. A large mismatch between incidence data of sectors at national level can be counterproductive in fostering intersectoral work.

Laboratories, Patient Management and Information

District laboratories are at the forefront in identification of new brucellosis patients and newly infected livestock herds. Several high-incidence countries, notably in Central Asia, have established laboratory systems for first level referral for presumptive brucellosis cases in districts, with referral of positive cases to a higher level. As stated above, district human and animal health authorities should regularly cross-check their findings, and further communicate with social service actors in charge of health information dissemination. Countries with well-established district-level serology laboratories using standard agglutination tests should maintain these. Staff require training in interpretation of serology results, including consideration of history of exposure to livestock and livestock products. Positive titres are commonly consistent with active brucellosis if accompanied with clinical signs and history of potential exposure. In endemic regions, asymptomatic individuals may have positive titres, and setting the threshold one titre higher provides sufficiently high specificity (WHO, FAO and OIE, 2006). Staff should be aware that it is not straightforward to identify chronic brucellosis cases (including relapses and recurrence) with standard agglutination tests. Further clarifications could be done at a higher level, given that these laboratories would have validated testing schemes to differentiate presumptive acute and chronic brucellosis. As was highlighted by other authors, national reference strain and sera banks and collaborations with reference laboratories are recommended for the validation and standardization of diagnostic tests used (Díaz *et al.*, 2011). A testing scheme could also include differential diagnosis of patients with history of exposure and clinical symptoms, but brucellosis seronegative test results, for instance including Q-fever diagnostics, which is another zoonosis with occurrence zones that overlap those with brucellosis transmission.

More microbiologists and molecular biologists should be trained in biosafety, brucellosis isolation (ideally, also with selective culture media providing better culture yield and less contamination), on how to store and safely ship strains, and in identification of the species of circulating *Brucella* spp.

In Kyrgystan, the S19 vaccine was applied in the 1990s for both cattle and small ruminants (Kasymbekov, 2016). It could be assumed that transmission of *B. abortus* in cattle was interrupted, but S19 hardly protected sheep and goats against *B. melitensis*. Presumably, even after these campaigns, infection in small ruminants remained. For several years now, Kyrgyzstan has vaccinated small ruminants with Rev.1. Recent human brucellosis cases are suspected to have been exposed by cattle (Kydyshov Kalysbek, 2019, unpublished data). In the absence of isolates, it is not known if cattle are infected with *B. melitensis* through spillover from small ruminants (Kasymbekov *et al.* 2013), or if cattle would maintain infection without continued spill-over from small ruminants (Godfroid *et al.*, 2014). A clarification of the epidemiological situation in people and livestock using isolates is urgently needed to decide how to best invest resources for control.

In laboratories with containment procedures to prevent contamination of samples, PCR with *Brucella* spp. DNA from cultures can provide a complementary identification and typing method based on specific genomic sequences (OIE, 2016).

In countries with Rev.1 vaccination, doctors and veterinarians should negotiate where and when it is of interest to do PCR-based testing allowing for the differentiation of field and vaccine strains (Lopez-Goni *et al*., 2011).

Brucellosis patient costs for transportation to diagnosis, treatment, hospitalization and ambulatory treatment, as well as for the follow-up examinations, are in many instances fully borne by patients, which can easily lead to a financial burden for families, particularly when, as frequently occurs, more than one member becomes ill from brucellosis. In addition, these patient households have diseased livestock with loss of income (livestock abortions, reduced milk production or culling of animals). The financial burden of brucellosis may delay diagnosis and treatment of patients, and households might want to sell livestock despite them being brucellosis positive. Public health agents are challenged to decide if drugs should be provided free of charge to the patients within patient management plans.

Information campaigns on realistic prophylactic measures by the communities should be evaluated regarding performance and benefit-costs. Most likely, they are a good investment. Studies on human brucellosis cases showed that often basic hygiene measures such as not contacting abortion material with bare hands were not respected. Involvement of social scientists could provide better understanding of risk behaviours and perceptions of the communities and expectations of authorities and identify locally adapted practices to reduce exposure to brucellosis and other zoonoses, including the consumption of unpasteurized dairy products, handling of abortion materials and lack of hand-washing practices after contact with livestock (Fig. 20.1). Context-adapted health promotion was implemented in Kyrgyzstan before the introduction of small ruminant vaccination. In those regions with health promotion, human brucellosis incidences decreased, whereas they continued to rise in regions without health promotion (Schüth *et al*., 2014).

Animal–Human Brucellosis Transmission Models

In Mongolia, based on 10 years of official livestock serological data and routine reporting of human brucellosis cases, the first livestock–human brucellosis transmission model was developed (Chitnis *et al*., Chapter 12, this volume). Livestock–human transmission dynamics and the effects of mass vaccination of livestock on animal and human disease cannot be captured by linear statistical models. They are governed by non-linear processes, which require a mathematical approach. Time-series brucellosis data from animals and humans can be used to develop animal–human mathematical transmission models. A simple compartmental deterministic model of livestock brucellosis transmission was developed, based on Mongolian government data on reported human cases and livestock serological data from 1990 to 1999 (Zinsstag *et al*., 2005). The model provided the mechanism for the simulation of animal–animal and animal–human transmission and measurement of the estimated effect of animal vaccination on human brucellosis incidence (Fig. 20.2). It can be observed that the number of human cases decreases at varying rates depending on the proportion of livestock immunized. An intervention in livestock thus indirectly reduces the number of human brucellosis cases.

The small ruminant–small ruminant transmission constant (contact rate between infectious and susceptible individuals) was 13 times higher than the small ruminant–human transmission constant. The cattle–cattle transmission constant was 165 times higher than the cattle–human transmission constant. The cattle–human transmission constant was five times lower than the small ruminant–human transmission constant. If the transmission constants were corrected for between-animal transmission, the cattle–human transmission efficiency was less than 10% of the efficiency of small ruminant–human transmission. These findings indicated that in the given Mongolian livestock production system and husbandry practices, *B. abortus* was less easily transmitted to humans than *B. melitensis* and that the principal source of infection for people was small ruminants.

This should be interpreted with some caution, considering the risk of bias and under-reporting in routinely reported data and the difficulty in interpreting brucellosis serological data. Out of 11 Mongolian human brucellosis strains from a recent study, ten were *B. melitensis* and one was *B. abortus* (Baljinnyam, 2014), which would support the above observations. In the above model, the spillover of *B. melitensis* to cattle (and camels) was omitted. The spillover of *B. melitensis* and/or *B. abortus*

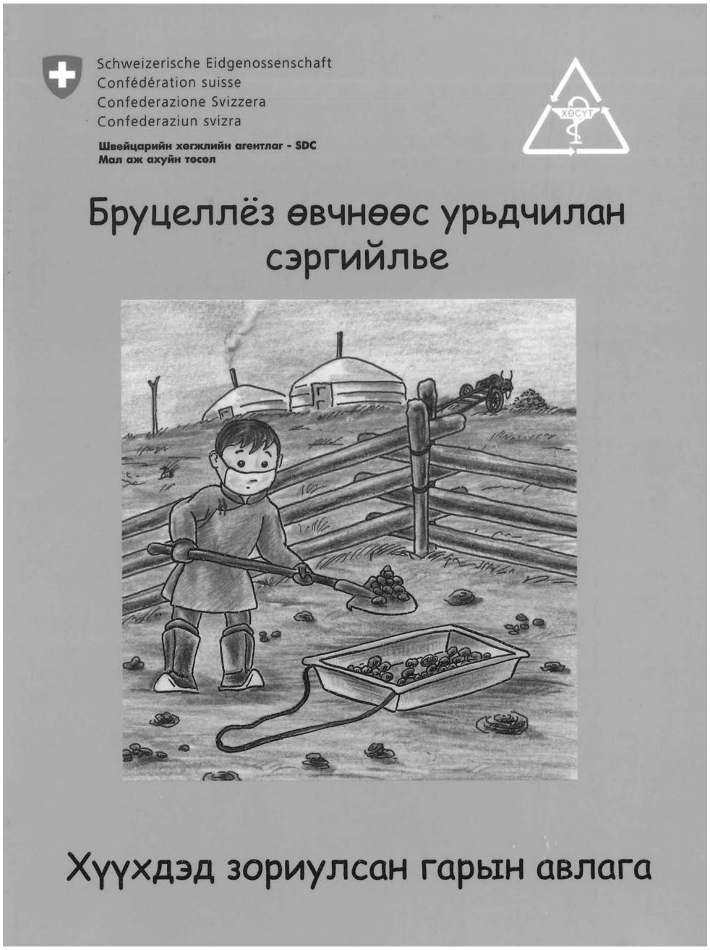

Fig. 20.1. Booklet for Mongolian schoolchildren depicting measures to reduce brucellosis exposure.

to camels could be included when more data are available on the proportion of *B. melitensis* and *B. abortus* isolated from Mongolian ruminants and camels. To date, only *B. abortus* was isolated from camels and surveys indicate that brucellosis seropositivity in camels is most closely related to cattle, but more evidence is still needed (Bayasgalan *et al.*, 2018).

Livestock–human brucellosis transmission models combined with molecular epidemiological studies provide insight into the interface between humans and animals and allow quantification of the disease transmission dynamics between livestock, humans and reservoir hosts. At the same time, such models serve as a backbone to a cross-sector economic analysis.

Cross-sector Economics of Brucellosis

Brucellosis results in public and private health costs as well as major losses to livestock production. These costs vary in a non-linear way depending on the intensity of transmission or the effectiveness of an intervention as captured by animal–human transmission models (Roth *et al.*, 2003). Based on the work of Roth and colleagues, cross-sector economic analysis was further refined to capture One Health benefits of other zoonoses including foodborne infectious diseases (Häsler *et al.*, 2014; Canali *et al.*, 2018; Häsler *et al.*, Chapter 10, this volume).

Brucellosis mainly affects herd fertility and reduces milk production, however, there is little

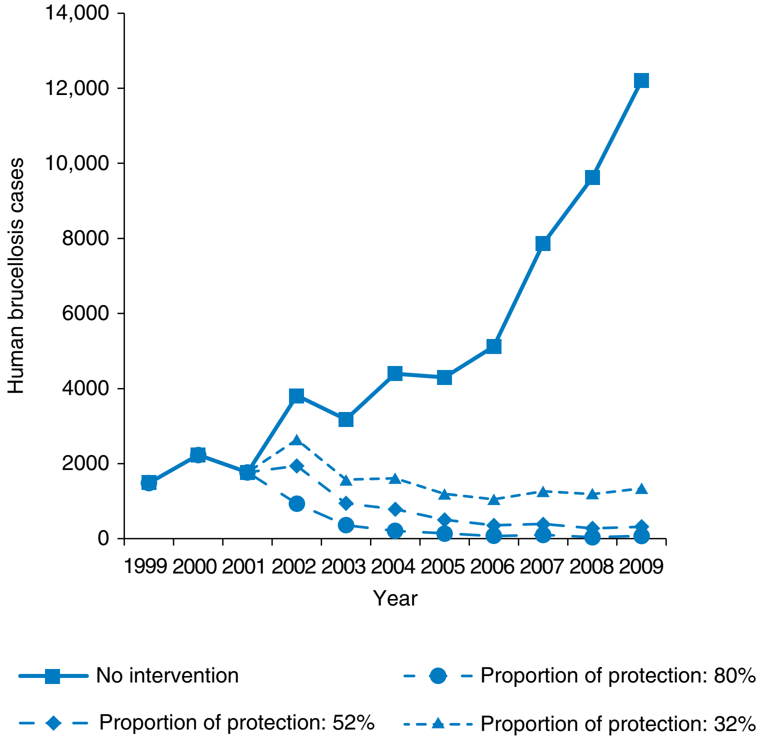

Fig. 20.2. Effect of livestock brucellosis vaccination of small ruminants and cattle populations on human annual cumulative incidence. Adapted from Zinsstag *et al*., 2005.

sound information available on the impact of brucellosis on livestock production (Bernués *et al*., 1997). In susceptible pregnant animals, most may abort in an 'abortion storm'. Subsequently, the frequency of abortions will be low under endemic circumstances. For the purpose of demographic simulation, we relate an overall reduction of fertility to brucellosis seroprevalence. The reduction of fertility (i.e. the annual calving rate per fertile female in a herd with brucellosis) can be calculated as baseline fertility f multiplied by a prevalence-dependent decrease (Eqn 20.6). For example, if the baseline fertility is 75% calving per fertile female/year, the overall fertility of a herd with a 10% seroprevalence and a 15% decrease of fertility because of abortions would be 73.9% (Bernués *et al*., 1997).

$$f_{\text{disease}} = f_{\text{baseline}}(1 - (\text{proportion of decrease} \times \text{seroprevalence})) \qquad (20.6)$$

Such a decrease in fertility may appear small, but it has a significant effect on total animal numbers and livestock product availability such as meat and milk. For the estimation of losses to livestock production, comprehensive livestock demographic models are needed (Shabb *et al*., 2013).

Costs to human health and livestock production can be combined in a broader framework for assessing the economic impact of brucellosis. The disease impact is assessed as costs to human health and livestock production both at the household and at national levels (Narrod *et al*., 2012; McDermott *et al*., 2013). For assessment of interventions, reduced health costs and improved livestock production are valued against the cost of the intervention in terms of profitability. The cost-effectiveness of an intervention or, in other words, the cost to achieve a reduced burden of illness in people, is expressed as the cost per number of disability adjusted life years (DALYs) averted.

Depending on the zoonosis and context, financial societal and national benefits can also extend beyond the health sectors and private households, for instance tourism and national exports (see Aenishaenslin *et al*., Chapter 9, this volume; and Häsler, Chapter 10, this volume, for more on how to include further benefits of zoonoses control). Costs of intervention delivery could be shared with other livestock interventions to reach remote livestock-keeping families. Incremental costs and benefits of combined control measures, for example brucellosis livestock vaccination along with foot and mouth disease (FMD), anthrax or peste des petits ruminants (PPR), could be estimated. However, owing to the neglected status of brucellosis in field research, there are no known published trials showing the safety and efficacy of simultaneous immunization against brucellosis and other national livestock vaccination diseases, despite that the FAO (Food and Agriculture Organization of the United Nations) identified this as a priority several years ago.

The advantage of a One Health economic assessment is that it reveals broader societal benefits and options for cost-sharing scenarios between different sectors. While mass vaccination of livestock against brucellosis is not profitable in the public health sector alone, it becomes profitable if the benefits to all sectors are cumulated (see Shaw *et al*., 2017; and Häsler *et al*., Chapter 10, this volume, for further description of costs and benefit sharing between sectors). An overall benefit would not be apparent without a cross-sectoral human and animal economic analysis.

Development of government policies requires careful identification of the main stakeholders, who may be outside the health sectors (Kimani *et al*., 2016). Stakeholders may further require demonstration of the efficacy of interventions (e.g. the use of conjunctival versus subcutaneous livestock vaccination) within a country or a livestock production system.

Control of Brucellosis

If brucellosis is present in livestock, mass vaccination of livestock should be the first option, regardless of the number of animals infected. It is more safe and best practice for female animals to be vaccinated using eye drops (conjunctival vaccination) rather than subcutaneous administration (Blasco, 1997). It is essential that vaccination takes place before the mating season, as vaccinating pregnant sheep can induce abortion. Vaccine-induced abortions are more severe following subcutaneous vaccination in sheep and goats. Unlike in northern countries, seasonality of mating and pregnancies is not a given for African small ruminants. This is a current barrier to planning of small ruminant vaccination in Africa, unless there were a new efficacious vaccine that does not induce (or more rarely induces) abortions (Ducrotoy *et al*., 2017). In cattle, female animals of all ages can be vaccinated but not males (Zinsstag *et al*., 2011).

Different reservoir species require different types of vaccine: (i) sheep and goats should be vaccinated with *B. melitensis* Rev.1; and (ii) cattle and yaks with an attenuated *B. abortus* S19 strain. It is important to first have an epidemiological overview in livestock, including camels if present, and people with surveys linking human and livestock data as well as serology with isolation/characterization of *Brucella* strains. When small ruminants are infected with *B. melitensis* and cattle with *B. abortus*, vaccination campaigns should be established with both Rev.1 and SP16 strain vaccines from the beginning.

Sharing of experiences between countries within regions has to be encouraged. In Central Asia and Africa, with frequent cross-border mobility of pastoralist herds, regional control programmes should be planned.

Effective interventions against brucellosis must be supported by certain enabling conditions. These include: (i) a clear governmental control policy and advocacy mechanisms; (ii) public and/or private veterinary services with the capacity to deliver in a timely manner (before the mating season) full coverage of the vaccination scheme; (iii) sufficient capacity of human health and veterinary laboratories at district, provincial and central levels; (iv) livestock census data to plan for sufficient quality vaccines; (v) for test and slaughter, a compensation scheme for livestock owners and a livestock registration system; (vi) a monitoring system of intervention outcomes to take corrective actions; and (vii) broad acceptance of the interventions in the communities.

One Health brucellosis studies inform policy and control programmes, advocating for much stronger collaboration between human and animal health sectors and other related disciplines. The development of a health-related government policy often first requires demonstration of financial benefits of health interventions as well as a possible sharing of disease intervention costs especially in low-income and transition countries (Marcotty *et al*., 2009; Zinsstag *et al*., 2012). Continuous provision of adapted information should be an integral part of a policy and planned in the cost estimation for intervention. Responsibilities for information sharing and dissemination are shared between the sectors.

Veterinary services (public and private) need to fully cover the geographical area of intervention at the right time (e.g. before the mating season). However, veterinary services can be overstretched with other obligations such as global efforts to eradicate PPR or control of FMD. It is not yet clear if vaccination campaigns can be combined, so most countries with mass livestock vaccination schemes against brucellosis plan for single vaccine campaigns. Furthermore, veterinarians and community animal health workers need adequate training and equipment to protect themselves. In northern countries seasonality of mating season is more evident, although the period may overlap with transhumance to summer pastures, when it is more difficult for veterinarians to access the herds.

New incentive schemes for private veterinarians, who are the main implementers of mass livestock vaccinations in countries with a control policy (i.e. in Asia and less so in Africa), have to be reviewed to reach the needed vaccination coverage. This implies that they still have a financial benefit rather than a loss. Expenditures to reach dispersed herds before the mating season may be high, but payment may be reduced, for instance when only vaccination of young stock is planned but veterinarians are paid per vaccinated animal. The costs and time to reach one herd is the same whether all animals or only young stock are vaccinated. Furthermore, veterinary services (public or private) need to be adequately equipped and compensated to maintain the cold chain for vaccines from vaccine storage through to administration.

The key role of human health and veterinary laboratories is described above. When interventions are implemented, they need enough capacity to handle the samples for monitoring.

The planning of full coverage in designated areas requires the availability of needed vaccine doses according to the livestock population. To plan ahead for the timely availability of sufficient doses to reach the needed coverage implies that a livestock census is done in the last couple of years. If vaccines are produced in the country (when there is adequate technical capacity, high-level biosafety and stringent quality control) vaccines must to be cooled at the production site, requiring reliable electricity (Baljinnyam, 2014).

If test-and-slaughter is implemented (e.g. often towards the end of mass livestock vaccination campaigns) public funds to compensate farmers for culled stock and a relatively corruption-free environment is a necessary condition. When farmers are not compensated, they may sell infected animals illegally, thereby contributing to continued transmission of brucellosis. Mobile livestock production systems, including nomadic or transhumant practices, allow intermixing of tested and untested herds, which renders a test-and-slaughter approach almost impossible. A livestock registration and identification system could help, but practical and less costly systems lag behind implementation schedules. In the absence of such livestock registration systems, the proactive involvement of butchers communicating with veterinary authorities is good practice to better ensure that no seropositive-tested animals at markets are further traded or reach consumers for consumption.

The recording of new human cases provides additional information on campaign effectiveness. The number of new human cases should drop, although this will not be immediate, as infected animals are not culled and remain in herds at the beginning of vaccination campaigns. In addition, livestock vaccination campaigns raise awareness of the disease, and, in the short term, more human patients may present themselves to health centres. The capacities of the primary health centres for human patients, in view of the necessary human resources, diagnostic tools and drugs for treatment, need to be continuously monitored after the start of livestock vaccination. The additional need for diagnostic/treatment capacity should be anticipated and accounted for. The incidences of human brucellosis should be monitored throughout and after implementation of the vaccination campaign to show the impact on the human burden of disease.

A mass vaccination campaign should be monitored by surveys independently from vaccination teams to have unbiased assessments. Randomized surveys can take place 3 weeks after vaccination to assess the proportion of reported vaccinated animals and serologically immunized animals. A comprehensive follow-up of mass vaccination campaigns and the monitoring of human cases provide the necessary information on the overall effectiveness of livestock mass vaccination. District and provincial veterinarians and physicians should be trained in basic epidemiology and practical conduction of surveys, when possible together, to establish ties enabling them to plan, run and analyse joint vaccination coverage surveys and to make recommendations on corrective actions of the campaigns.

Involving communities and local authorities in development of acceptable vaccination schemes creates ownership and encourages adherence to jointly decided activities. Behaviour change communication strategies should be carried out in parallel to epidemiological interventions within the context of the control programme.

Conclusions

No one claims that brucellosis control is straight forward, but the benefits to society of control measures for human and animal health are documented. The authors fully acknowledge that the practical aspects, including budgeting and cost sharing, need time to be resolved. In the rare cases where there is a confirmed wildlife reservoir, this will add more complexity and take more time. When treating or being specialized in one zoonotic disease, as here for brucellosis, one should remain open to other prevailing human and animal health priorities rather than succumb to silo thinking: single disease programmes can also be regarded as vertical approaches, despite being coordinated across sectors (Schelling *et al.*, 2015). A One Health approach contributes to brucellosis control at various levels, creating added value that can only be achieved by human and animal health working closely together:

1. Joint human and animal surveys and surveillance more holistically clarify the epidemiological situation, including animal species that are to a lesser extent apparent at the start (pigs, camels and wildlife), and identification of gaps (such as effective human patient management) and synergies between the sectors (e.g. laboratories) because they trigger iterative processes between stakeholders as well as field work and laboratory. Joint surveys and surveillance should reduce the time to detection of the main source of human infection and thereby allow more targeted control interventions and estimation of the level of under-reporting.
2. Molecular epidemiological studies, including *Brucella* strains isolated from humans and animals in the same setting, importantly narrow the source of human infection.
3. Information campaigns carried out by all key stakeholders, including social services, public health and veterinarians, are likely to more effectively reach at-risk populations and create commitments for long-lasting results of control efforts.
4. Livestock–human transmission models demonstrate and quantify the effect of interventions in animals on public health, which cannot be shown by studying transmission in humans and livestock in isolation.
5. Cross-sectoral economic assessment of brucellosis control by mass vaccination of livestock demonstrates that, from a societal point of view, brucellosis control is cost-beneficial, whereas from a public health perspective alone, it is not. However, economic models should increasingly account for other intervention costs that are derived from inclusion of other sectors, such as continued information campaigns, leverage of veterinary services to deliver vaccination services or assistance for human patient households struggling to cover diagnosis and treatment costs. The practical issues/gaps to tackle are also best identified in cross-sectoral assessments to provide a basis of broader negotiation.
6. One Health brucellosis studies inform policy and control programmes as well as behaviour change strategies, advocating for much stronger collaboration between human and animal health sectors and other related disciplines, including possible sharing of disease intervention costs. One Health approaches clearly provide additional insights, which are of eminent practical relevance for control and elimination of brucellosis.

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21 Human and Animal African Trypanosomiasis

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Introduction

Management of zoonotic disease risk arising from interactions between animals, humans and the environment, demands integrated action from both human and animal health sectors, support from other sectors with a stake in health governance and key inputs from the environmental sector (Cook *et al*., 2004; Okello *et al*., 2011; Welburn, 2011; Zinsstag *et al*., 2012). Prevention of disease is preferable in the longer term but demands sustained financial commitments that are difficult to maintain when the health impacts are not acknowledged – a major issue for control of neglected zoonotic diseases (Maudlin *et al*., 2009). Here we focus on human African trypanosomiasis (HAT) and animal African trypanosomiasis (AAT) and describe the evolution of a One Health approach – the Stamp Out Sleeping Sickness (SOS) campaign – that has been key to sustainable of control zoonotic *Trypanosoma brucei rhodesiense* human African trypanosomiasis (rHAT) in Uganda.

Human African Trypanosomiasis

A re-emerging disease

HAT or sleeping sickness refers to two diseases of significant public health importance across much of sub-Saharan Africa for over a century. HAT is difficult to diagnose and treat and fatal in the absence of treatment. Acute rHAT, which results in death within 6–12 months, occurs within the extensive tsetse fly belts of sub-Saharan Africa to the east of the African Rift Valley, while chronic *T. b. gambiense* (gHAT), which results in death many years after infection, occurs to the west (Welburn *et al*., 2001a). The site of disease acquisition plays an important role in determining approaches to diagnosis, treatment and control (Fig. 21.1; Wastling and Welburn, 2011).

HAT is now considered an endemic or re-emerging disease, being characterized by periodic large-scale outbreaks separated by periods of lower transmission. However, for much of the 20th century HAT was pandemic, with major epidemics emerging across Africa resulting in a terrifying narrative of an untreatable disease, with serious social and economic consequences, not unlike current fears of pandemic influenza, but one for which unique One Health solutions developed (Okello *et al*., 2014). The recent decline in the numbers of new cases of sleeping sickness highlighted by the World Health Organization (WHO) (Simarro *et al*., 2008) indicates we are entering an inter-epidemic period. However, data on HAT cases are subject to significant underreporting and the potential for the disease to return in epidemic proportions remains high (Fig. 21.2; Welburn *et al*., 2016).

Uganda's unique position

Uganda is the only country in Africa with disease foci for both rHAT and gHAT. Acute HAT was first reported to have emerged in Busoga in 1896, causing a great epidemic around the shores of Lake Victoria (Koerner *et al*., 1995; Févre *et al*., 2004). In 1905, a chronic form of the disease was reported in West Nile, Uganda (Maudlin, 2006). For over a century, the two disease foci have remained confined to their traditional, separate geographical

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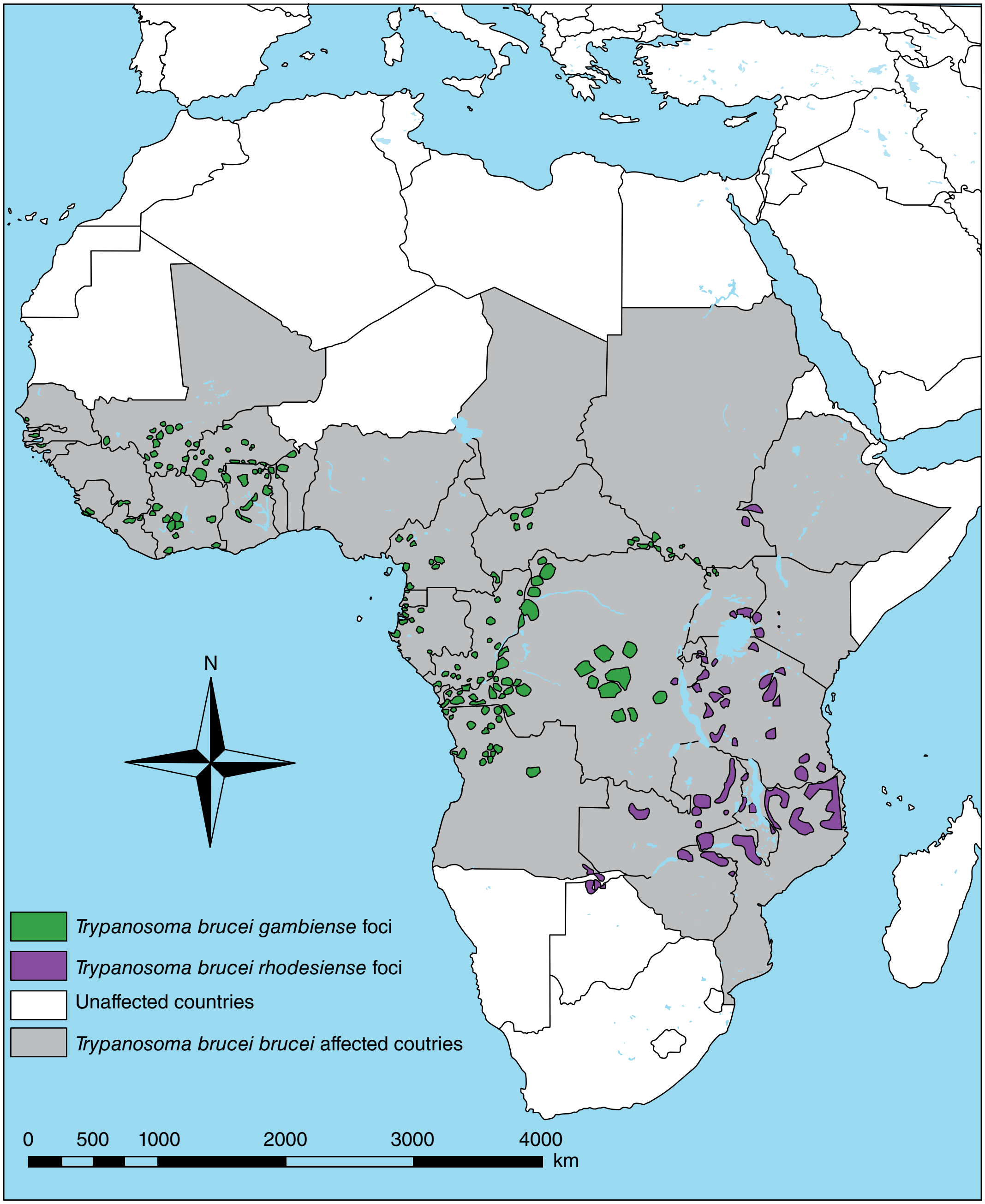

Fig. 21.1. Human African trypanosomiasis (HAT) foci across sub-Saharan Africa. Adapted from Welburn *et al.*, 2001a.

foci, rHAT in south-east Uganda and gHAT in the north-west, close to the Sudanese border. Many agencies have been involved in extensive surveillance, diagnosis, treatment and control (Welburn *et al.*, 2001a,b; Welburn and Maudlin, 2012). There was concern in the 1970s that gHAT would spread southwards within the tsetse fly belt with human population movements, particularly mass movements of people to and from internally displaced person (IDP) refugee camps. However, while

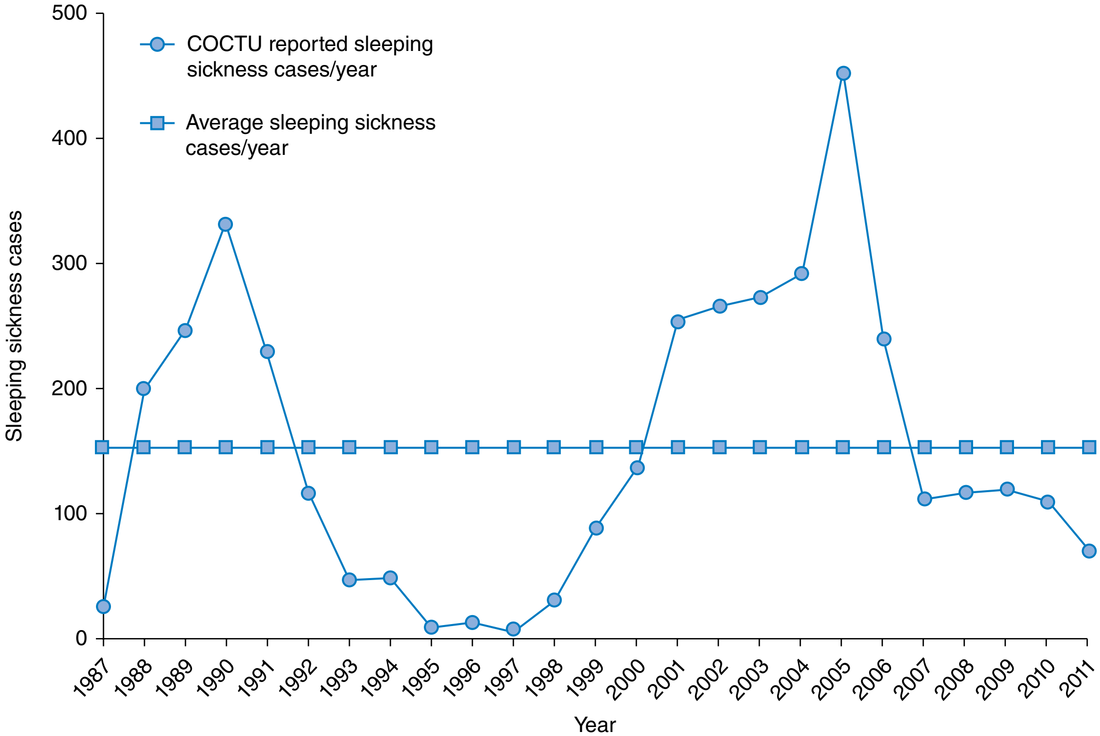

Fig. 21.2. Incidence of HAT in Uganda from 1987 to 2011, characterized by periodic large-scale outbreaks separated by periods of lower transmission. From the Coordinating Office for Control of Trypanosomiasis in Uganda (COCTU), 2011, unpublished.

gHAT foci expand and contract, cases have been largely limited to localized HAT foci.

Under-reporting and the hidden burden of disease

Both forms of HAT are difficult to diagnose and are largely under-reported (Odiit *et al.*, 2005; Févre *et al.*, 2008a,b). There are many more individuals infected than are reported leading to fears of a silent hidden burden of infection (Wastling *et al.*, 2011; Welburn *et al.*, 2016). HAT deaths are also under-reported since people affected are often beyond the reach of health-care systems (Odiit *et al.*, 2004). Under-reporting is as high as 40% in some areas affected by rHAT; for every reported HAT case, 12 remain undetected. It is estimated that 92% of HAT deaths in Uganda are unreported due to confusion with malaria and other infectious diseases (Odiit *et al.*, 2005).

To estimate the current burden of disease in Uganda, official figures for rHAT were used to calculate a baseline average number of human cases per year; from this an average disability adjusted life year (DALY) burden per case can be calculated using standard WHO/World Bank methodologies as applied to rHAT (Févre *et al.*, 2008b). Conservatively, these numbers are estimated at around 800 human cases/year, based on government records from 1987 to 2011 (average of 160 reported cases/year) and an 80% under-reporting conversion factor (taken from published literature), with an average of 18.8 DALYs per case (Fig. 21.2 shows details). An 80% under-reporting is considered conservative, as medical services are estimated to identify less than 10% of HAT cases using the present means of surveillance (Odiit *et al.*, 2005).

HAT as a zoonosis – animal reservoirs of infection

T. b. rhodesiense is a significant zoonosis which infects a wide range of non-human wild and domestic animal hosts (Anderson *et al.*, 2011; Auty *et al*., 2012). The presence of human infective parasites in animal blood has long been established from work with human volunteers who were infected with parasites derived from wild and domestic animal hosts (Onyango *et al*., 1966). However, while wild animals form part of the parasite reservoir in Zambia (Anderson *et al*., 2011) and Tanzania (Auty *et al*., 2012), in south-east Uganda, where game animals are no longer common, cattle serve as the major reservoir for rHAT (Welburn *et al*., 2001b; von Wissmann *et al*., 2014).

Measuring the extent of the domestic animal reservoir of zoonotic *T. b. rhodesiense* was previously complicated by the fact that cattle are often also infected with non-human-infective *T. b. brucei*, which are morphologically indistinguishable from *T. b. rhodesiense*. In 2000, a single gene was identified (serum-resistance-associated (SRA) gene) that can differentiate human infectivity in *T. brucei sensu latu* parasites (Xong *et al*., 1998). The SRA gene can be used as a genetic marker to distinguish between *T. b. brucei* and *T. b. rhodesiense* and identification of human infective parasites in animals became possible (Welburn *et al*., 2001b). Using the SRA marker, up to 18% of cattle in Soroti District were found to be infected with *T. b. rhodesiense* (Welburn *et al*., 2001b), compared with 1% using previous methods (Hide *et al*., 1994). Tsetse flies exhibit a strong feeding preference for cattle (Waiswa *et al*., 2006), and the risk of becoming infected by a fly infected from a cow is five times more likely than from a fly infected from a human (Hide *et al*., 1996).

Risk and consequences of overlap of two forms of HAT in Uganda

Identification of HAT and the type of treatment given is simply based on knowing which types of sleeping sickness focus the patient originated from and the stage of the disease (Welburn *et al*., 2001a; Wastling and Welburn, 2011). For stage I *T. b. rhodesiense* HAT, patients are treated with suramin (discovered in 1921) and for *T. b. gambiense* with pentamidine (discovered in 1941). For both forms of late-stage HAT, patients can be treated with melarsoprol (discovered in 1949) but there is considerable resistance of *T. b. gambiense* to this drug and patients are now more often treated with Eflornothine (registered in 1990). Fexinidazole, the first all-oral treatment for both stages of *T. b. gambiense* HAT (Baker and Welburn, 2018) was more recently added to the WHO's Essential Medicines List for adults and children over 6 years of age.

In Uganda, there was concern that the gHAT would spread southwards, particularly via mass movements of people to and from refugee camps. The public health consequences of convergence of the two forms of HAT have significant cost implications; should the two forms of HAT coalesce then diagnosis and treatment of HAT, already problematic, would become almost impossible, compromising disease management in terms of diagnosing the parasite responsible, applying the different recommended treatments and selecting appropriate control policies.

The spread of HAT in Uganda

In Uganda, cases of acute HAT were confined to the south-east of the country until 1985, when the disease began migrating northwards at a rate of one district/year. In December 1998, a case of human sleeping sickness was reported in Soroti District, which was north-west of the documented extent of the *T. b. rhodesiense* focus; this was the first case in areas north of Lake Kyoga and 70 additional cases presented over the following 18 months. Limited tsetse fly control measures were implemented, but the outbreak was not contained and by June 2000, 119 cases had been recorded. New cases of HAT were still being reported in Soroti in 2005, bringing the total reported cases to over 400 and, by extrapolation, total reported and unreported cases to over 700 (Févre *et al*., 2005). The disease subsequently spread across Lake Kyoga into Kaberamaido District (Batchelor *et al*., 2009; Wardrop *et al*., 2013). By 2005, cases of gHAT and rHAT were only 150 km apart (Picozzi *et al*., 2005) raising significant concern among researchers and policy makers that the two forms of HAT would converge.

Disease drivers – infected livestock – infected people

The northward migration of the rHAT focus in Uganda was surprising; between 1985 and 2005 there had been large investments in vector control (tsetse fly trapping) and active human disease surveillance activities supported by a series of large-scale European Union control programmes. Active disease surveillance is highly effective for both forms of HAT. Trapping tsetse flies is less effective in Uganda within *T. b. rhodesiense* foci – infected tsetse flies are rare since flies can only become infected if they are susceptible (Welburn and Maudlin, 1991) and provided they take in the infection at their first meal (Welburn and Maudlin, 1992, 1999; Soumana *et al*., 2012). Furthermore, even if susceptible flies do feed on an infected host, development of the infection and progression from the fly gut to develop into mammalian infected forms is not a certainty; cyclical transmission is sex-linked, male flies transmitting significantly more infections than females (Milligan *et al*., 1995; Welburn *et al*., 1995). Most parasites ingested by tsetse flies die in the midgut and are not transmitted (Welburn *et al*., 1996). At the height of an epidemic of *T. b. rhodesiense* in Tororo district, only 1:1000 flies were found to be infected, with typical daily trap catches ranging between zero and five flies per trap (or per km^2).

For animal surveillance, microscopy-based techniques do not detect the low levels of trypanosome infection observed in cattle in HAT endemic regions (Picozzi *et al*., 2002; Magona *et al*., 2003). While polymerase chain reaction based methods are available for best practice to assess trypanosome prevalence (AAT and HAT parasites) in cattle (Cox *et al*., 2010; Ahmed *et al*., 2011, 2013), veterinary screening teams continue to use microscopy methods that fail to detect the risk of transmission from domestic livestock.

A case-controlled study showed a strong association between the HAT cases in Soroti District and proximity to a local cattle market known as Brookes Corner (Févre *et al*., 2001). Distance from Brookes Corner was a highly significant risk factor ($P < 0.001$) but as time progressed distance from the market became less of a risk factor. It was estimated that more than 50% of the cattle being traded at this market had come from the *T. b. rhodesiense* endemic zone to the south, making cattle the most likely cause of the outbreak. Surveys confirmed that the domestic animal reservoir was the primary source of human infective trypanosomes for tsetse flies, with up to 40% of cattle carrying *T. b. rhodesiense* in south-east Uganda (Welburn *et al*., 2001b). While pigs (Okuna *et al*., 1986) and dogs can also be infected, pigs are relatively short lived and do not present long-term disease reservoirs while dogs are quickly killed by the disease. In Uganda, treating only cattle would, therefore, significantly reduce *T. b. rhodesiense* infection (Welburn *et al*., 2006). Between 1998 and 2006, uncontrolled movements of infected cattle resulted in zoonotic rHAT being introduced to eight new districts in Uganda (Fig. 21.3; Févre *et al*., 2005; Picozzi *et al*., 2005).

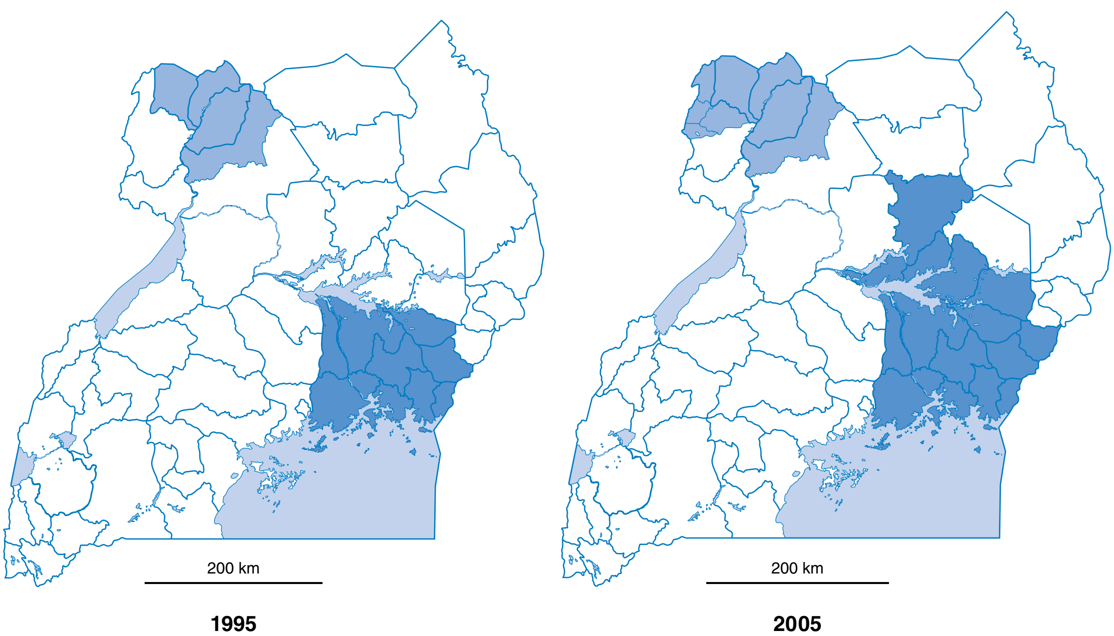

Fig. 21.3. Convergence of HAT foci 1995–2005. Dark blue, *Trypanosoma brucei rhodesiense*; mid-blue, *T. b. gambiense*; light blue, water bodies. Adapted from Picozzi *et al*., 2005.

The politics of restocking and disease instability

In the late 1970s, Karamojong pastoralists intensified cattle raiding (Epelu-Opio, 2009), leading to depopulation of Teso District and abandonment of farming (Hutchinson *et al*., 2003). The 'Teso Wars' (1986–1992) caused widespread disruption in Soroti and Kaberamaido districts (Epelu-Opio, 2009). In the late 1990s, people began to return to the area, assisted by government and donor-driven large-scale cattle restocking programmes (Selby *et al*., 2014). In June 2003, a brutal insurgency by the Lord's Resistance Army spread south-east towards Lira, Apac, Kaberamaido, Katakwi and Soroti districts resulting in much of the population being displaced to refugee camps. To support repopulation, these districts benefited from large-scale restocking interventions, from non-governmental organizations (NGOs) and the World Bank/government Northern Uganda Social Action Fund (NUSAF), implemented through district veterinary officers (under the African Development Bank-funded National Livestock Productivity Improvement Programme (NLPIP)). Many cattle purchased for restocking were sourced from districts endemic for *T. b. rhodesiense* including Kamuli, Palissa, Tororo and Mbare districts in south-eastern Uganda and most restocking activity failed to comply with existing strict disease controls for cattle moving between districts (Selby *et al*., 2014). Uncontrolled movement around Lake Kyoga of infected cattle, not treated with trypanocides at the point of sale, resulted in zoonotic HAT being introduced to eight new districts of Uganda between 1998 and 2006 into communities unaware of the disease.

Insecurity in Southern Sudan also impacted on migration of zoonotic HAT-infected animals northwards in Uganda. In 2008 livestock traders and agents from Southern Sudan were buying cattle from as far south as the Ochero market, Kaberamaido District to supply the meat trade in Juba.

One Health Approaches to HAT in Uganda

The emergence of a One Health platform

Uganda is unique in its early development of a One Health framework for coordination of animal trypanosomiasis and human sleeping sickness control that cuts across human health, animal health and the environment. The Coordinating Office for Control of Trypanosomiasis in Uganda (COCTU) is the governmental body responsible for coordinating and monitoring HAT interventions in Uganda. COCTU is the Secretariat of the Ugandan Trypanosomiasis Control Council (UTCC) formed by a parliamentary act in 1992, a permanently funded interministerial platform that coordinates policy for all stakeholders involved in tsetse fly and trypanosomiasis control in Uganda. COCTU is a concrete example of a One Health platform working in practice (Okello *et al*., 2014). Seated within Uganda's Ministry of Agriculture, Animal Industries and Fisheries (MAAIF) and endorsed by the Office of the Prime Minister for almost three decades, COCTU is evidence of Uganda's foresight and commitment to One Health, long before the approach became fashionable. COCTU coordinates sleeping sickness policies, provides linkages to work and research in the field and collates data.

Establishment of COCTU was in part driven by the resurgence of a major *T. b. rhodesiense* epidemic in the late 1980s, where significant human and financial inputs necessitated a change from the disaggregated silo approach of past control programmes.

The genesis of Stamp Out Sleeping Sickness (SOS) – WHO round table

In response to reports in 2005 that the two forms of sleeping sickness were only 150 km apart (Picozzi *et al*., 2005) COCTU asked the WHO for technical support to address the threat of the merger of *T. b. gambiense* and *T. b. rhodesiense*. A meeting, supported by the WHO Special Programme for Research and Training in Tropical Diseases (TDR), was held during the 28th ISCTRC (International Scientific Control for Trypanosomiasis Research and Control) in Addis Ababa, Ethiopia in 2005 and a resolution (The WHO Regional Office for Africa (WHO/AFRO) Regional Committee resolution – AFR/RC55/R3) recommended that WHO/AFRO should support implementation of the regional strategy for HAT control and prevent further spread of the disease (Morton, 2009).

Trypanocidal drugs would be used to eliminate the reservoir of *T. b. rhodesiense* infection in domestic cattle within the newly affected districts, previously shown to be successful in Kamuli District (Fyfe *et al*., 2016), and this would be followed up with application of deltamethrin spray to cattle to prevent reinfection by tsetse fly (Kajunguri *et al.*, 2014). Acute rHAT would be rolled back through south-eastern Uganda to prevent the merger of the two forms of sleeping sickness while building up sustainable AAT control at the local level. The shortage of veterinary resources following downsizing of the civil service was a constraint, and the option of using final-year veterinary students to deliver services was a way of addressing this. This action was viewed as an open-ended process, involving an emergency intervention followed by interventions taken by farmers themselves to provide sustainability.

SOS – a public–private partnership for human African trypanosomiasis

On 1 June 2006, a Memorandum of Understanding was drafted and signed by the Chairman of UTCC and by representatives of the pharmaceutical company Ceva Sante Animale and Industri Kapital (IK), a private equity firm with a charitable arm (IKARE). Makerere University and the University of Edinburgh were contracted to implement block treatment and related activities and to work through local distributors to introduce insecticidal treatment of cattle. This laid the foundations for what was to become the Stamp Out Sleeping sickness (SOS) campaign – a public–private partnership.

SOS focused on the use of trypanocidal drugs to eliminate human infective parasites in the animal reservoir and application of insecticides to the tsetse fly predilection sites of cattle to prevent reinfection. Stakeholders included cattle owners, district veterinary officers, the Faculty of Veterinary Medicine at Makerere University, Uganda, The University of Edinburgh, the corporate sector, local private sector companies, donors and national regulatory authorities. Prior to the launching of the SOS campaign, members of COCTU and their technical committee met in Kaberamaido with the entire District Council, plus council staff and members of the public and visited IDP camps and villages.

SOS aimed to treat 85% of the cattle in five districts in northern Uganda that were at risk of disease overlap and prevent merger of gHAT and rHAT foci (Welburn *et al.*, 2006). Modelling indicated that treating at least 85% of the cattle population could eliminate human-infective parasites given that half of all tsetse feeds were taken from cattle (Welburn *et al.*, 2006). Over 2 months approximately 250,000 cattle were treated across five districts. In high-risk districts (Dokolo and Kaberamaido) cattle were treated with isometamidium chloride (Veridium®), which has a prophylactic effect against trypanosome infections for up to 3 months. Cattle in Lira, Amolatar and Apac were treated with diminazene aceturate (Veriben B12®), which is curative, but offers no prophylactic effect against new trypanosome infections.

To prevent reinfection, cattle were protected using deltamethrin-based insecticides. When applied to a sufficiently large proportion of cattle, insecticides can provide a sufficiently even level of treated cattle per hectare to control tsetse flies at a population level, turning the cattle into live baits (Hargrove *et al.*, 2002). Whole-body treatment of cattle or the use of pour-on applications is prohibitively expensive for farmers, but since tsetse flies preferentially feed on the legs and belly of cattle, treating only these parts, the so called 'Restricted Application Protocol' (RAP), is cost-effective (Torr *et al.*, 2007). By application of insecticide at normal dip concentration to only tsetse fly feeding predilection sites, protection can be delivered at a fraction of the cost of a whole-body treatment (as little as US$0.02 per head of cattle) (Kabasa, 2007). Only 1.1% or 1.6% of village cattle/day need to be treated, equating to 21% herd whole-body application or 27% RAP for $R_0 < 1$ (Kajunguri *et al.*, 2014; Muhangizi *et al.*, 2014b). RAP protects against a range of tick-borne diseases such as theileriosis, anaplasmosis and cowdriosis and tick damage, endemic to this region (Magona *et al.*, 2008, 2011; Muhanguzi *et al.*, 2014a).

For SOS cattle were sprayed with the deltamethrin-based insecticide (Vectocid®) spraying only the legs and belly (and the ears for tick control) to prevent reinfection (Fig. 21.4) and application was recommended to be applied monthly to provide full protection against reinfection. Monthly application of RAP after trypanocidal treatment was shown to maintain prevalence at < 1% of all trypanosomes in Tororo District, which is endemic for both HAT and AAT (Brownlow, 2007). After the initial treatment, insecticide was left with district veterinary officers for them to undertake a second and third free spraying, and communities were supported by an educational and awareness campaign – through radio messages and posters on the importance of continuing to administer the treatment on a regular basis in the districts concerned.

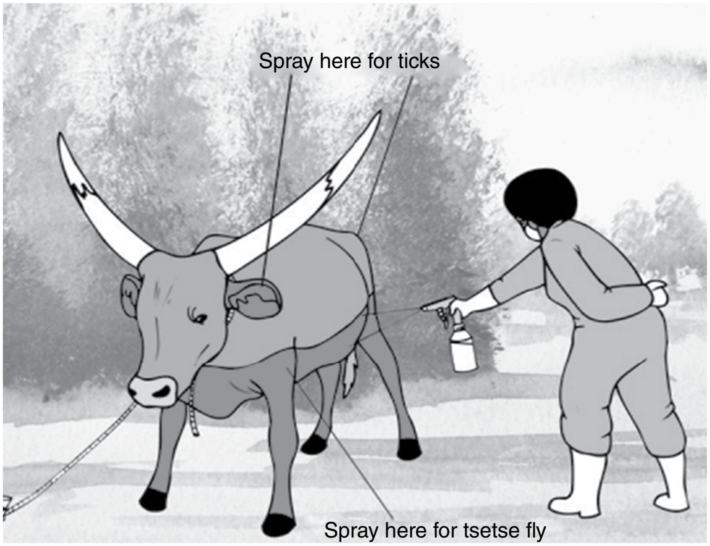

Fig. 21.4. Restricted Application Proctocol (RAP) for insecticide treatment on cattle.

SOS built a One Health platform for sustainability, educating farmers and key stakeholders about the close links between animal health and human health and economic development. In order to provide human resources to support the SOS campaign, Makerere University offered the opportunity for final-year veterinary students to engage with the community, preparing graduates for private veterinary practice and addressing the need for alternative private sector mechanisms to deliver field-level service. The Veterinary Faculty at Makerere University revised their curriculum to accommodate lecture-free periods and launched the MinTracs programme in which students are deployed to work with communities to undertake treatment, spraying, sampling and interviews as part of their final year of study.

Outcomes from the SOS public–private partnership

At the inception of SOS, spatial analysis showed that *T. b. brucei* and *T. b. rhodesiense* were distributed in cattle throughout four of the five districts of the SOS target area (see Fig. 21.5, top and bottom left). The initial phase resulted in a reduction of the prevalence of the sleeping sickness parasite in the cattle by close to 70% and human cases of HAT by 90% and a 75% reduction of all trypanosomes in cattle (human and cattle pathogens) (see Fig. 21.5, top and bottom right) and halted the northerly expansion of *T. b. rhodesiense* HAT focus. The impact of the intervention was greater in *T. b. rhodesiense* since there is a fitness cost to being human infective (Coleman and Welburn, 2004; Welburn *et al.*, 2008). The amount of *T. brucei* in cattle is related to risk of human infection (von Wissmann *et al.*, 2014; Fyfe *et al.*, 2016); reductions in *T. b. rhodesiense* in cattle were reflected in a reduction in the number of sleeping sickness cases recorded within the SOS target area. From 1:100 cattle infected with *T. b. rhodesiense* (by SRA analysis) before treatment, samples showed a reduction to 1:1000 post-treatment.

Over the period in which the SOS campaign was in operation, the number of reported HAT cases fell in four out of the five SOS target districts, with no cases reported from Apac. Post-treatment human cases were only observed clustered near to cattle markets (Batchelor *et al.*, 2009) and a second phase of cattle treatments was introduced. The reduction of cases in Lira indicates that the barrier between the two forms of sleeping sickness has been maintained and the northerly movement of *T. b. rhodesiense* sleeping sickness had been halted.

A sustainable community-based spray network

Relatively modest levels of treatment (~20% of animals, even where tsetse fly numbers are not

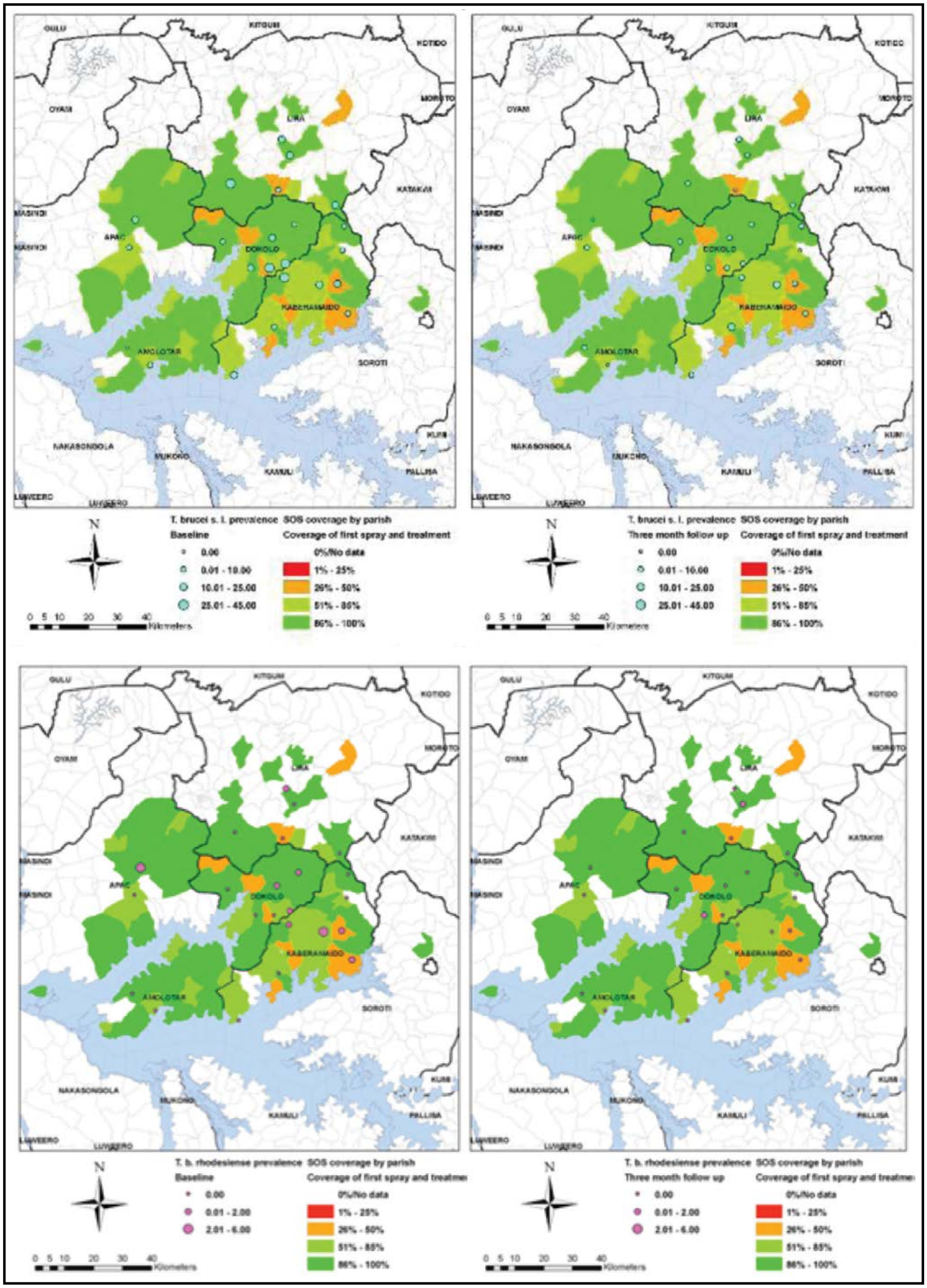

Fig. 21.5. Impact of mass drug treatment on *Trypanosoma brucei sensu latu* and *T. b. rhodesiense* in village cattle. *T. brucei s.l.* before (top left) and 3 months after mass treatment with trypanocides (top right); and *T. b. rhodesiense* before (bottom left) and 3 months after mass treatment with trypanocides (bottom right).

reduced by the intervention) are predicted to result in elimination of HAT in south-east Uganda (Hargrove *et al*., 2012). Furthermore, treating a reasonable proportion of cattle with insecticides can lead to total eradication of the disease; only 1.6% of village cattle need to be treated with RAP/day equating to 27% maintained coverage of RAP for $R_0 < 1$ (Kajunguri *et al*., 2014). Farmers need to protect cattle from tick-borne diseases, and coverage targets are achievable and affordable. If a sustainable spray market can be developed, tsetse fly-transmitted trypanosomiasis will cease to be a problem and rHAT can be eliminated.

Initiatives put in place by the private-sector SOS partners (IKARE and Ceva Sante Animale), including mobile spray teams and the start-up of private veterinary practices and drug shops in previously unserved areas aimed to develop a sustainable network for Uganda. Individual sprayers were recruited to form a community-based network of independent micro-entrepreneurs with support and training provided by their local veterinarian. Ensuring reliable and affordable access to quality drugs is a key part of developing a commercially sustainable network. Farmers were encouraged to spray their cattle every 2 weeks or more frequently for tick control and at least once a month for tsetse flies using RAP methods.

As a result, it is estimated that at least 1 million animals are currently being regularly sprayed using RAP in high-risk districts (Waiswa and Wangoola, 2019). A similar number are estimated to be treated with whole-body application of deltamethrin-based products, sufficient to control both animal and human trypanosomiasis at the village level. Farmers report that treated animals were healthier, more productive and better fed; animals are also protected against a range of other tick-borne diseases such as theileriosis, anaplasmosis and cowdriosis.

The establishment of a network of community-based spray teams in Uganda provides a model for the long-term prevention of parasite reinfection and should ensure the gains of mass treatment campaigns are maintained. Ensuring reliable and affordable access to quality drugs is a key to developing a commercially sustainable network. For insecticide-treated cattle targets to be achieved, however, farmers need to use products that work against both ticks and tsetse flies rather than products that are only active against ticks (Bardosh *et al*., 2013) and some farmers are still using tick-only products. There is a case to be made for putting in place acaricide zoning in HAT-affected and HAT-at-risk zones.

Added Value of a One Health Approach

Socio-economic impact of the SOS campaign – an 'averted disaster'

Estimations of *total societal burden* of emerging and endemic zoonoses (the combined human and animal +/– environmental costs of disease for the public and private sectors including indirect impacts on food security of smallholder farmers and micro- and macroeconomic impacts of disease on livestock productivity losses and health) can provide compelling evidence for the value of operationalizing One Health (Narrod *et al*., 2012), but estimates are not available for most neglected zoonotic diseases (Häsler *et al*., Chapter 10, this volume).

A number of calculations were made to assess the economic impact of the scenario where the two forms of HAT came to overlap – the 'averted disaster'. Human-health gains as a result of reduced parasite prevalence can be quantified from this in terms of: (i) sleeping sickness cases averted; (ii) DALYs averted (with value in terms of cost in US dollars); and (iii) care costs averted. Calculations were made on a series of assumptions: levels of non-reporting, numbers of patients reporting at first and second stage, survival rates of the disease and patterns of spread based on available evidence.

Assumptions about the rate at which an unchecked epidemic would expand are based on previous experience and expert opinion. In 2009, without the SOS intervention, it is likely that we would have experienced some 4000 new cases (the majority under-reported). The WHO suggests these would triple annually; in this projection, we conservatively assume they would double. The figures of between 0.4 and 1.6 million DALYs averted (or extra life years gained) are realistic. In addition, between US$15 million and US$60 million of health-care expenditure for patients and the health services have been saved (A. Shaw, 2009, unpublished data; see Table 21.1). These figures provide a first-level assessment of how much the averted disaster might have cost and indicate the large range of values that highlight the difficulties of this type of 'what if' calculation. They show that the SOS programme resulted in savings to the health services, protecting rural livelihoods and saving people's lives (Table 21.1).

Table 21.1. Health implications in terms of human life and money for a 20-year cycle can be saved by Stamp Out Sleeping Sickness (SOS) approaches for four scenarios regarded as likely by WHO experts. From A. Shaw, 2009, unpublished data.

Maximum annual number of new cases	Year reached	What happens thereafter	Million DALYs averted	US$ million health costs saved	Economic[a] total: US$ million saved
30,000	2012	Reduce by 1/3 each year	1.55	57.63	367.25
20,000	2012	Reduce by 1/4 each year	1.14	42.53	275.47
20,000	2012	Reduce by 1/2 each year	0.75	28.17	194.88
10,000	2011	Reduce by 1/2 each year	0.39	14.50	103.25

[a]Discounted at 5% per annum and valuing 1 DALY at US$340.

For animal health, cost is a major issue, not just for livestock keepers but also for policy makers in the field of tsetse fly control. Recent estimates of how insecticide-treated cattle (ITC) and particularly the restricted application (RAP) version of ITC compare with other methods of tsetse control indicate that it can be substantially cheaper (Shaw *et al*., 2014). Animal productivity gains as a result of reduced parasite prevalence can be quantified in terms of HAT parasite-free cattle and tick-free cattle. The application of RAP to maintain AAT animals can result in an average gain of US$20 per bovine/year (maximum US$30–40 per fertile female or working bull). Combining this with costs of tick-borne diseases in traditionally managed cattle (Minjauw and McLeod, 2003) indicates that benefits would be in the region of US$34 per head/year. This translates into a gain of approximately US$9000–10,000/km^2 of 'productive land'/year while animals are protected (Shaw, 2009).

The loss of an animal in these communities increases vulnerability in these households. The fact that animal health is linked to human welfare as a route out of poverty needs continual reinforcement. In the model adopted by the SOS campaign, it is recognized that the curative elements of the programme – the mass treatment of cattle to remove trypanosomes – should be free of charge to cattle keepers. However, spray treatment to maintain reduced levels of HAT are largely the financial responsibility of cattle keepers. To be accepted by cattle keepers, the latter has to be affordable to purchase, easy to acquire and must demonstrate a rapid benefit (Butcher, 2009).

Scaling the SOS One Health approach

SOS oversaw the mass treatment of 250,000 cattle in five high-risk areas undertaken in 2006–2007. In 2010–2012 the programme was extended to cover an additional 175,000 cattle in market hotspots and in two additional districts (see Fig. 21.6). These treatments demonstrated significant reductions in both human and animal pathogens. However, to eliminate the threat of *T. b. rhodesiense* HAT in Uganda the reservoir of infection must be eliminated at scale.

Fifty districts of Uganda are at risk from one or the other form of HAT mostly in poor, rural areas. Nine of these districts account for 80% of all cases of zoonotic *T. b. rhodesiense* HAT recorded over the last 25 years (see Fig. 21.7).

Following on from the demonstrated success of the SOS approach to disease control, the aim is to follow this up to reduce *T. b. rhodesiense* HAT across high- and lower-risk districts in Uganda. The high-risk zone includes districts historically affected by *T. b. rhodesiense* HAT and districts in which humans are currently at risk of infection. The lower-risk zone includes districts in which there have not been any reported cases of *T. b. rhodesiense* HAT but from which reinfection and/or overlap of the two strains of disease is a potential risk. These include the districts currently affected by *T. b. gambiense* HAT and the contiguous districts (highlighted low-risk areas in Fig. 21.8).

Ideally, a sustainable One Health approach would comprise an initial 3-year mass-cattle treatment programme – injection and spray – to quickly reduce human-infective parasite prevalence in cattle. Community-based spray teams will sustain gains achieved through mass treatment by delivering insecticide treatment to cattle in high-risk areas. The impact of the proposed intervention will be evaluated in terms of effective delivery of the mass treatment programme in years 1–3 and a consequent reduction in the human-infective parasite prevalence rate in cattle in years 4–8.

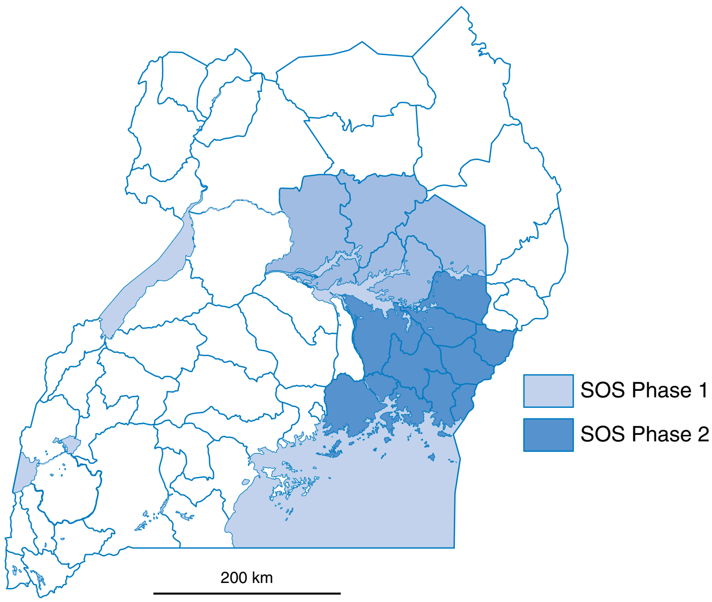

Fig. 21.6. Districts treated by the Stamp Out Sleeping Sickness (SOS) campaign.

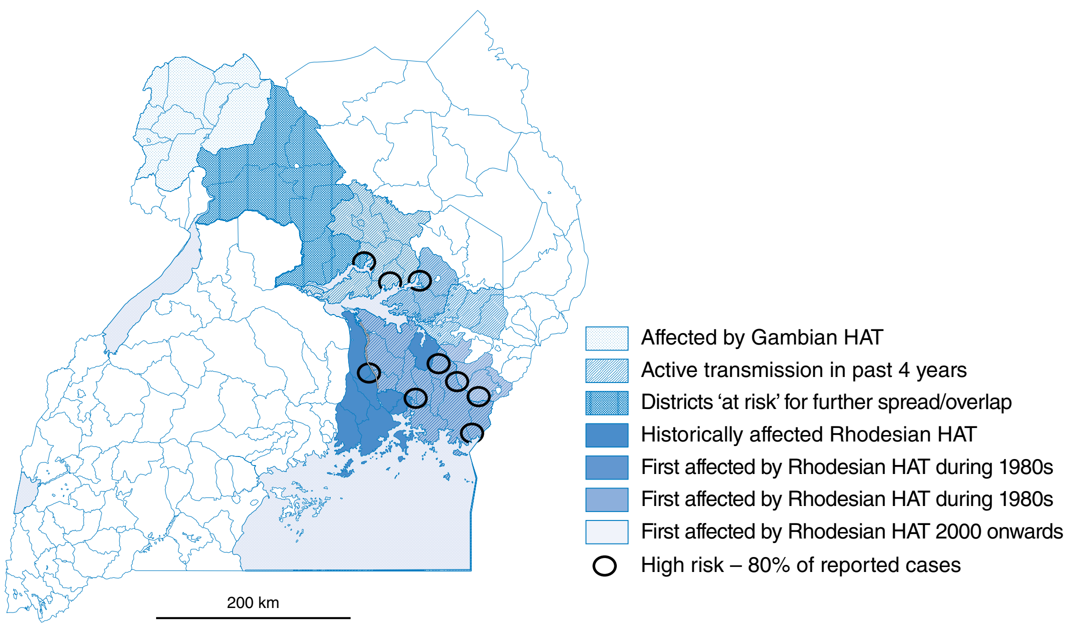

Fig. 21.7. Sleeping sickness status for districts of Uganda.

Development Impact Bonds – a new approach to funding disease control

Prevention of disease outbreaks is preferable and less costly in the longer term but requires dedicated financial commitments that become difficult to sustain when the health impact, or consequences of emerging zoonoses, is not realized in global terms, as for HAT. There is significant and growing interest

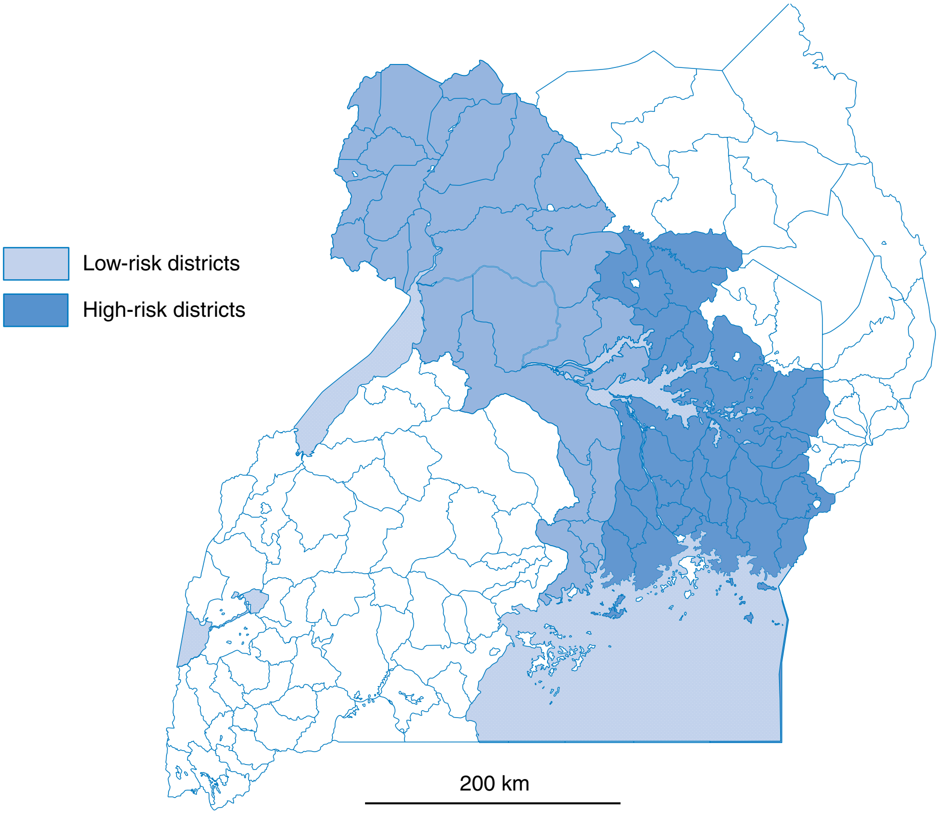

Fig. 21.8. Districts targeted for mass treatment.

among traditional development donors and philanthropic institutions and the emerging class of impact investors in the use of Development Impact Bonds (DIBs) to more effectively deliver impact in developing countries (Center for Global Development and Social Finance, 2013). DIBs use private investment to provide upfront risk capital for development programmes, only calling on donor funding to repay capital, plus a potential return (i.e. premium), once clearly defined and measured development outcomes are achieved. DIBs have the potential to attract new capital from impact investors motivated by both social and financial returns. By transferring the risk of programme failure to these investors, DIBs bring a greater focus on implementation and delivery of successful results. In this way, DIBs also satisfy the growing demands for publicly funded aid. If the outcomes are not met, the investors absorb the loss, but if they are met, international donors repay the investors, with interest. Investors therefore have a strong incentive to manage their risk by bringing rigour and discipline to the DIB process. This should increase the likelihood of achieving both the social outcome and the financial return. DIBs offer an attractive sustainable financial model for the neglected zoonoses (Welburn *et al.*, 2016). A DIB for HAT could provide the investment that Uganda lacks to tackle HAT at scale.

A framework for exploring the economic benefits of scaling disease control

To design a DIB, it is necessary to understand the dynamic links between control activities at scale and economic benefits unlocked by controlling zoonotic HAT in Uganda. A framework has been developed to simulate the effects of the proposed interventions (mass deployment of drug therapy and insecticide spraying of cattle followed by the expansion of routine spraying of cattle) on changes in parasite prevalence in cattle (the main outcome indicator) and to link it to the impact, quantified as a reduction in human health burden (expressed as DALYs), reduced health-care costs (expressed as US dollars) and improvement in animal health (expressed as US dollars). The framework needed to be sufficiently flexible to examine a variety of different intervention structures and all possible treatment coverage, predict the temporal dynamics of changes in prevalence and thus impact, describe the quantitative relationship between the outcome indicator (changes in *T. brucei* prevalence in cattle) and impact (DALYs plus US dollars) over the long-term period of the DIB and provide a robust basis for payment triggers based on changes in the outcome indicator.

The core of the framework is a detailed epidemiological model of *T. b. rhodesiense* transmission by tsetse flies among cattle and humans (based on Kajunguri *et al.*, 2014) that allows different control interventions to be modelled with costs associated to different levels of coverage achieved. The intervention assumptions feed into the epidemiological model that in turn predicts the dynamic changes in parasite prevalence in cattle (*T. b. brucei* and *T. b. rhodesiense* – although we could also extend the model to track the more cattle pathogenic trypanosome species of *Trypanosoma congolense* and *Trypanosoma vivax* for completeness) and also incidence of HAT in humans. The epidemiological model outputs are translated to human cases and health-care costs averted, estimated from the literature and adjusting for the proportion of case reporting to the health-care system rates (Odiit *et al.*, 2005; Févre *et al.*, 2008b; Häsler *et al.*, Chapter 10, this volume).

For animal health benefits, the model permits calculation of the number of cattle days free of trypanosomes (relative to the baseline equilibrium prevalence), which are translated into dollars gained, estimated from the burden of cattle trypanosomiasis (see Shaw, 2009; Shaw *et al.*, 2014). Similarly, the model allows us to work out the cattle days covered with insecticide, which can be linked to an improvement in animal health through reducing tick-borne disease (estimated from Shaw *et al.*, 2014).

The model framework can be used to design an epidemiological outcome measure and sampling system that monitors changes in *T. brucei* prevalence in cattle and links these to DIB outcome payments trigged at agreed levels of impact. The outcomes, specifically, DALYs averted, health-care costs avoided and economic gains due to improved animal health and productivity, are dynamically driven by the epidemiological model, so the model framework can be used to examine the costs and benefits associated with all possible coverage levels of drugs and insecticides delivered in a variety of different scenarios. An example of the model outputs is shown in Fig. 21.9 and Tables 21.2 and 21.3.

Moreover, the framework allows us to quantify the relationship between prevalence of *T. brucei* in cattle (a tractable, verifiable indicator that can be measured with pre-agreed statistical accuracy) and the impact of the interventions (DALYs averted and US dollars saved, which are difficult and costly to measure directly). In this way, the framework can be used to design an epidemiological outcome measure and sampling system that monitors changes in *T. brucei* prevalence in cattle and links these to DIB outcome payments trigged at agreed levels of impact.

The framework developed here for HAT, in which the economics of disease control are dynamically linked to the epidemiological changes resulting from control efforts, is essential in exploring the non-linear relationships between outcomes and inputs. This approach is essential in fully exploring the One Health costs and benefits associated with scaling disease control efforts and applicable to other zoonotic disease systems, including rabies, that will behave in a highly non-linear manner when interventions are implemented (Welburn *et al.*, 2017).

Social Finance launched their third DIB including two investments directly related to the Sustainable Development Goals and neglected tropical diseases (NTDs). These are the Cameroon Newborn DIB to roll out Kangaroo Mother Care, an evidence-based programme of skin-to-skin care to improve neonatal health outcomes in ten hospitals across Cameroon, and the Cambodia Rural Sanitation DIB with the goal of 1600 villages claiming Open Defecation Free status, while increasing rural sanitation coverage to 85% in target areas by 2023.

The detailed work on planning a DIB for rHAT, documented here, was done under a UK-Aid Department for International Development (DFID) pilot programme. Unfortunately, the outcome funding was not made available for deployment of the DIB as an operational intervention. At the time of writing, there is yet to be a DIB dedicated to controlling an NTD despite a compelling rationale for

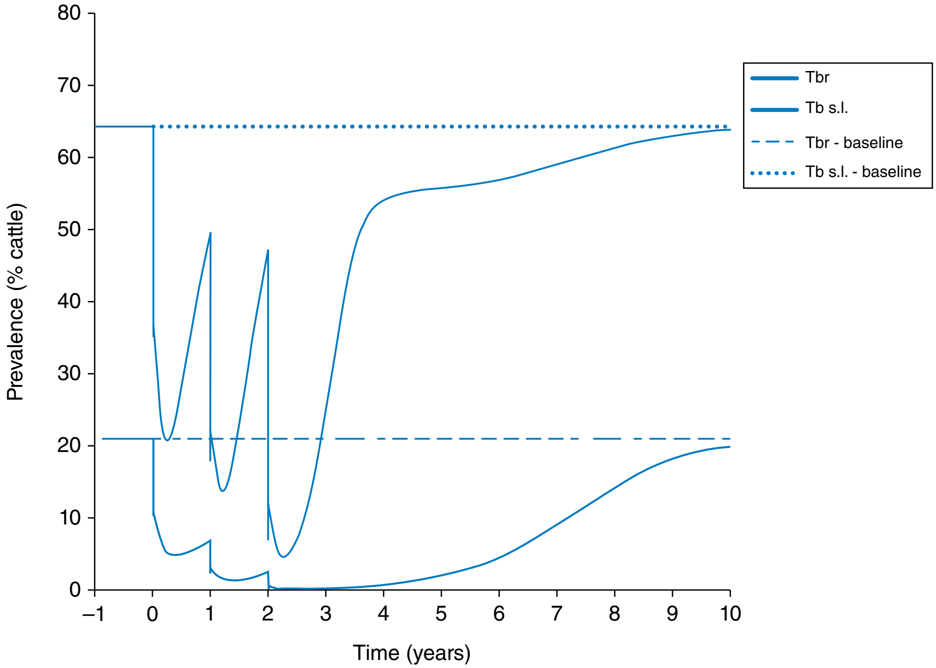

Fig. 21.9. Outputs from the framework linking the epidemiology and economics of disease control. Simulated changes in the prevalence of *T. b. rhodesiense* 'Tbr' and *T. brucei sensu latu* 'Tb s.l.' in cattle with (solid lines) and without (broken lines) intervention. The intervention assumes three rounds of mass treatment of cattle with trypanocidal drugs and insecticide spray with coverage levels of 50% (time = 0 year), 65% (time = 1 year) and 85% (time = 2 years) of all cattle.

the suitability of DIBs for financing to infectious disease control (Welburn *et al.*, 2016).

Discussion and Conclusions

The fearful narrative that developed of HAT as an untreatable disease, with serious social and economic consequences, which originally led to establishment of COCTU, was not dissimilar to fear of the rapid spread of avian influenza (H5N1) virus. This virus was responsible for HPAI (highly pathogenic avian influenza) that caused huge losses in poultry production with a direct negative impact on the livelihoods of the global poor (Vandersmissen and Welburn, 2014).

The potentially disastrous consequences of overlap of the two types of HAT was clear to decision makers, both specialist and non-specialist alike. Strong institutional networks, amenable to a One Health approach, were in place in Uganda, which allowed for an effective response to a crisis situation that would impact on the livelihoods of poor rural communities (Okello and Welburn, 2014). Without these established networks and mutual trust, backed up by a supportive coordination body at a high level within government, it is difficult to envision the mobilization of resources and the overcoming of legal and logistical hurdles in time to respond effectively to the northerly progress of the disease. Expressed as a crisis, there was a need for urgent decision making and imperatives to use available science.

The SOS campaign played a major role in terms of halting the northerly movement of *T. b. rhodesiense* and averting the potential crisis of the two forms of HAT converging. The One Health intervention deployed by SOS was based on sound science that clearly related the presence of human sleeping sickness or HAT to the presence of parasites in the animal reservoir, in this case, domestic cattle. Thus significantly reducing the prevalence in the animal reservoir using improved diagnostics and new application techniques would definitively result in less HAT.

Several factors were key to the evolution of SOS including: (i) the patterns of insecurity and responses

Table 21.2. Model predicted health-care benefits expressed as the number of sleeping sickness cases averted, the DALYs averted and health-care costs averted, assuming an annual baseline of 800 cases/year, based on an average of 160 reported cases and 80% under-reporting.[a]

Year	Sleeping sickness cases averted	DALYs averted	Care (US$) averted
1	584	10,956	116,856
2	737	13,816	147,354
3	790	14,819	158,051
4	783	14,687	156,648
5	756	14,178	151,217
6	691	12,963	138,261
7	561	10,528	112,288
8	371	6,965	74,285
9	191	3,588	38,264
10	80	1,509	16,089
Total	5,545	104,009	1,109,313
Discounted total (20% discount rate)	2,661	49,919	532,420

[a]Based on the methodology detailed in Févre *et al*. (2005) and Odiit *et al*. (2005), we estimate an average ~18.8 DALYs and ~US$200 health-care cost per case. This assumes the DALYs for a sleeping sickness death, late-stage diagnosed survivor and early-stage survivor are 23, 0.8 and 0.2, respectively, with the percentage of cases resulting in death, late-stage survival and early-stage survival being 81.1%, 12.5% and 6.4%, respectively. Associated costs of sleeping sickness deaths and survival through the different pathways (unreported, late-stage diagnosis and early-stage diagnosis, as in Shaw *et al*., 2014 and Shaw, 2009, unpublished).

that led to migration of HAT; (ii) a sense of urgency to prevent overlap of acute and chronic HAT; (iii) the existence of strong intersectoral mechanisms for coordination on AAT and HAT control; (iv) a realization of the consequences of decentralization of government services for animal health work; and (v) strong research evidence to support intervention and private sector support. Studies confirmed the potential of the methodology in maintaining a low prevalence of disease by spraying cattle and treating with appropriate drugs (Brownlow, 2007; Muhanguzi *et al*., 2014b; Hamill *et al*., 2017). The narrative used with farmers to deliver the impact focused on reducing tick burden and prevention of animal trypanosomiasis (nagana), bringing benefits to farmers in the short term. Dialogue between livestock keepers, communities and authorities to identify interventions that were acceptable, affordable and adequate embedded One Health at local, district and national levels (Butcher, 2009).

Sustaining One Health platforms such as COCTU should not be underestimated and is not without its challenges. Roles and responsibilities must be agreed upon by all stakeholders involved in One Health approaches, particularly regarding financial resource allocation. Ugandan ownership and the high-level political endorsement of COCTU and SOS demonstrates how One Health success is likely to be much more sustainable and appropriate when owned nationally (Okello and Welburn, 2014).

Table 21.3. The animal health-care benefits resulting from cattle days free of trypanosome infections, assuming an average ~US$15 per cow/year free of trypanosomes, and cattle protected from tick infestation from insecticide treatment, assuming an average of ~US$8 per cow/year protected with insecticide treatment. Health-care costs averted and animal benefits unlocked can be discounted. Assumptions are taken from Shaw, 2009.

Year	Trypanosome-free cattle years	Tryps US$ benefit	ITC years[a]	Tick US$ benefit	Total US$ benefit
1	725,441	10,973,522	53,652	401,617	11,375,139
2	798,079	12,072,301	69,748	522,102	12,594,403
3	1,204,087	18,213,861	91,209	682,749	18,896,611
4	289,976	4,386,378	0	0	4,386,378
5	6,855	103,693	0	0	103,693
6	98	1,483	0	0	1,483
7	1	21	0	0	21
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
Total	3,024,537	45,751,260	214,609	1,606,469	47,357,729
Discounted total (20% discount rate)	1,998,195	30,226,092	145,929	1,092,362	31,318,454

[a]ITC, Insecticide-treated cattle.

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22 Bovine Tuberculosis at the Human–Livestock–Wildlife Interface in Sub-Saharan Africa

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Introduction

The majority (60%) of emerging infectious diseases are zoonotic in nature and of these over two-thirds have a wildlife reservoir (Kruse *et al*., 2004; Chomel *et al*., 2007; Jones *et al*., 2008). Livestock diseases and epidemics challenge food security and threaten national economies (Perry and Grace, 2009). Livestock diseases globally cost US$200 billion in loss of trade, tourism and tax revenue for the 10-year period 2002–2012 (Cartin-Rojas, 2012).

The outbreaks of severe acute respiratory syndrome in China in 2002, Nipah in Malaysia and, more recently, Middle East respiratory syndrome are some zoonoses highlighting the importance of wildlife reservoirs for human health. This chapter focuses on bovine tuberculosis (BTB) in sub-Saharan Africa, another example of a pathogen transmitted at the human–livestock–wildlife interface. We describe how interfaces are multiple, fluid and dynamic in nature, and very poorly studied in the African context. The importance of wildlife in sub-Saharan Africa is highlighted, and the chapter concludes with a One Health approach to control the disease and illustrate societal benefit from the wildlife side.

Bovine Tuberculosis (BTB)

BTB is a bacterial disease found in humans, livestock and wildlife. It is caused by *Mycobacterium bovis*, which belongs to the *Mycobacterium* tuberculosis complex (MTC), a group of seven genetically and clinically closely related Mycobacteria species that show host preferences. Some MTC, such as the human-associated *Mycobacterium tuberculosis*, *Mycobacterium africanum* and *Mycobacterium canetti*, and the predominantly rodent pathogen *Mycobacterium microti*, are host specific, while others (*M. bovis*, *Mycobacterium caprae*) have a broader host range (Brosch *et al*., 2002; Mostowy *et al*., 2005; Smith *et al*., 2006; de Jong *et al*., 2010). Domestic cattle are the main host for *M. bovis* (Cosivi *et al*., 1998). However, a wide range of domestic and wildlife mammals can acquire the disease and act either as reservoir or spillover hosts (de Lisle *et al*., 2002). A reservoir host is defined as having a persistent BTB infection within the population even in the absence of a constant infection source and can thus transmit the agent to other species. Spillover hosts, on the other hand, have only limited capacity of maintaining disease in their populations when a persistent source of infection is absent (Renwick *et al*., 2007). Some classic examples of known wildlife reservoir hosts for BTB are the brushtail possum (*Trichosurus vulpecula*) in New Zealand, the Eurasian badger (*Meles meles*) in the UK and the African buffalo (*Syncerus caffer*) in Southern Africa (Coleman and Cooke, 2001; Rodwell *et al*., 2001; Griffin *et al*., 2005).

The main routes of tuberculosis (TB) transmission are by inhalation or ingestion of infected raw

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animal products (Cosivi *et al.*, 1998). In most industrialized countries, BTB has been eliminated or controlled through costly national test and slaughter programmes, decades of milk pasteurization and culling of wildlife populations. The latter showed controversial results (Thirgood, 2009; le Roex *et al.*, 2015). However, re-emergence of BTB has occurred, for instance in Spain and the UK, linked to existing wildlife reservoirs (Phillips *et al.*, 2003; Naranjo *et al.*, 2008; Richomme *et al.*, 2010; Gortazar *et al.*, 2011). The disease remains largely prevalent in sub-Saharan Africa, where the control programmes are often logistically and financially not feasible (Ayele *et al.*, 2004).

BTB in African livestock

BTB is endemic in sub-Saharan African cattle and has been reported in 42 of the 54 African nations (de Garine-Wichatitsky *et al.*, 2013). Prevalence varies across regions, breeds involved and husbandry type. Higher prevalence is generally found in exotic and crossbred stock, which are more susceptible to *M. bovis* than local breeds (Vordermeier *et al.*, 2012). Prevalence tends to be higher in intensive dairy systems (found usually in urban and peri-urban areas) than in traditional rural extensive husbandry systems (Fofana, 2003; Diguimbaye-Djaibé *et al.*, 2006; Müller *et al.*, 2008; Tschopp *et al.*, 2010c; Boukary *et al.*, 2011; Firdessa *et al.*, 2012; Swai and Schoonman, 2012). A single common TB ancestor is thought to have originated in Africa, most probably in East Africa, from which all members of the TB complex are evolved (Comas *et al.*, 2015). Three clonal complexes of *M. bovis* (European 1, African 1 and 2) have been characterized in African cattle to date, suggesting geographical clustering of the pathogen, which possibly sheds light on the evolutionary history of BTB in Africa (Müller *et al.*, 2009; Berg *et al.*, 2011; Smith *et al.*, 2011). For instance, European 1 clonal complex was isolated in cattle from Zambia, South Africa and Tanzania, suggesting pathogen movement between the UK and these countries (Smith *et al.*, 2011). The precise origin of both African clonal complexes is still unknown.

BTB in African wildlife

In Africa, the first cases of BTB in free-ranging wildlife were described in the early 20th century in Uganda and Southern Africa in African buffalos, warthogs and antelopes (Paine and Martinaglia, 1929; Gallagher *et al.*, 1972; Woodford, 1982a,b). Later, the African buffalo and the lechwe (*Kobus leche*) were found to be BTB reservoir hosts in Southern Africa (de Vos *et al.*, 2001; Caron *et al.*, 2003; Munyeme and Munang'andu, 2011). The disease has been confirmed in greater kudus (*Tragelaphus strepsiceros*) and warthogs (*Phacochoerus africanus*) (Michel *et al.*, 2006; Renwick *et al.*, 2007; Bengis, 2012). All wildlife mammals are susceptible to BTB. To date, BTB in sub-Saharan Africa has been described in at least two dozen wildlife species, including carnivores, omnivores and herbivores (Woodford, 1982a,b; Tarara *et al.*, 1985; Keet *et al.*, 2000; Cleaveland *et al.*, 2005; Michel *et al.*, 2009; Katale *et al.*, 2012). The number of species which host BTB is increasing, and the disease is thus referred to as a dynamic multispecies-host–pathogen system (Renwick *et al.*, 2007). Prevalence studies at the continental level, however, are still lacking and confirmed cases originate from only five countries in southern and eastern Africa. According to the World Organisation for Animal Health (OIE), 33 out of 54 (61%) countries have no data at all on wildlife BTB (de Garine-Wichatitsky *et al.*, 2013).

BTB in humans in Africa

BTB cases reported in humans are few, despite the disease being endemic in livestock, the close relationship between people and livestock in rural Africa, and the lack of milk pasteurization and meat inspection. A meta-analysis by Müller *et al.* (2013) showed that a median 2.8% of all TB cases in humans were attributable to *M. bovis* in Africa, with significant country variations. In Ethiopia, Firdessa *et al.* (2013) found a minimal *M. bovis* involvement in human TB (four out of 964 patients) despite high BTB prevalence in livestock. Transmission to humans through raw milk consumption seems also to be rare, probably due to inactivation of *M. bovis* because of the rapid fermentation processes which are commonly used (Kazwala *et al.*, 1998; Mariam, 2009). In a simultaneous human and cattle study in a pastoralist area of south-eastern Ethiopia, only three out of 163 human MTC isolates were *M. bovis*. One of them had the same spacer spoligotype as strains isolated from cattle in the same study area (Gumi *et al.*, 2012).

To date, there are no published reports of direct BTB transmission from wildlife to humans in Africa (de Garine-Wichatitsky *et al.*, 2013). The direct risks are likely to be similar to those originating from livestock, with the exception of raw milk consumption. Hence, people at risk would include game-meat consumers, veterinarians, taxidermists, hunters and park staff. However, it is most likely that human cases are under-reported due to the lack of data gathered on human disease burden, the lack of diagnostic facilities and poor disease knowledge, particularly from the wildlife side.

The Human–Livestock–Wildlife Interface

The concept of the human–livestock–wildlife interface and One Health has been discussed extensively in the last 15 years or so, with various definitions of One Health given. Here the definition used is any added value in terms of human and animal health, financial savings or environmental benefits from closer cooperation of human and animal health sectors at all levels of organization (Zinsstag, 2012; Zinsstag *et al*., Chapter 2, this volume). We hold that a human–livestock–wildlife interface is not a standard concept but rather one that varies tremendously across sub-Saharan Africa, depending on human, livestock and wildlife densities and movements (e.g. migration, transhumance), wildlife species, environmental factors and anthropogenic land-use change. Detailed knowledge of the epidemiology and ecology at a particular interface is therefore essential before embarking on a One Health programme.

Cattle densities

Domestication of livestock seems to date back 10,000 years in the Levant and Near East (Prins, 2000). The history of origin of the current African cattle breeds is still unclear and complex despite various theories (Hanotte *et al*., 2000; Ibeagha-Awemu *et al*., 2004). Livestock are thought to be exotic to sub-Saharan Africa, invading habitats abundant with native locally adapted wild ungulates around 4000–5000 BC and moving in a south-easterly route (Prins, 2000; Hanotte *et al*., 2002). Subsequent waves of *Bos indicus* cattle immigration from the east, European *Bos taurus* more recently during the colonial era, and indigenous *B. taurus* breeds, originating probably in northern Africa (Hanotte *et al*., 2002), further contributed to the current genetic make-up, and likely the disease pool of the current African cattle population.

Sub-Saharan Africa has very diverse ecosystems, climates, vegetation and endemic diseases, such as trypanosomiasis (see Welburn and Coleman, Chapter 21, this volume) and theileriosis, that are either conducive or not for agriculture and livestock keeping. Diseases and agroecological zones helped shape the agricultural landscape of Africa, leading to various livestock distributions and stocking densities. The pattern was further shaped in recent decades by climate change, with population declines in some arid areas (Lunde and Lindtjorn, 2013). East Africa holds over half of the total livestock population of sub-Saharan Africa, followed by West Africa (26.3%), Central Africa (5.8%) and Southern Africa (1.6%) (Ibrahim and Olaloku, 2000). Ethiopia and Sudan hold the largest share of the cattle population per country (FAOSTAT, 2014). These various livestock densities across the continent are likely to be an influencing factor for livestock–wildlife contact dynamics and infection pressure at their interface.

Cattle competition with wildlife

The coexistence between livestock, people and wildlife over millennia changed dramatically in the last half century as population growth exploded in Africa, leading to inevitable habitat and diet overlaps and competition between wild and domestic animals. The contact interface between animals and humans intensified rapidly, and continues to do so, as natural resources become scarcer. Natural habitats continue to be changed into agricultural land (Patz *et al*., 2004; Hibert *et al*., 2010). Wildlife has been extirpated, as it became a competitor to livestock, a nuisance (e.g. crop damage) or a threat (e.g. predation), leading to a dramatic decline in general wildlife populations all over the continent (Grootenhuis and Olubayo, 1993; Norton-Griffiths, 2000; Prins, 2000; Gordon, 2009; Maisels *et al*., 2013). Taxons related to the domestic bovid are particularly affected due to their similarity in physiology, ecology and biology (Gordon, 2009), which is consistent with the potential of infectious disease sharing between domestic cattle and their wild counterparts. In general, pathogen transmission from domestic animals to wildlife affects wildlife more severely than vice versa (Prins, 2000).

Role and importance of wildlife

In past decades, a lot of research was done on BTB prevalence in livestock, wildlife and humans in Africa. However, very few considered the interface of epidemiology, ecosystem and host ecology, and even less looked at disease prevalence simultaneously in livestock, humans and wildlife in the same areas (Munyeme *et al*., 2009; Tschopp *et al*., 2010a; Malama *et al*., 2019).

In many sub-Saharan countries, wildlife plays a minor role in the economy of the countries, which often results in low national budgets allocated for conservation and country priorities regarding their economy. A quarter of all people living on less than US$1/day reside in sub-Saharan Africa, and a high proportion of the continent's human population is food insecure (Kock, 2005). The livestock sector remains an economic priority for many African countries, where 80% of rural farmers and pastoralists are directly dependent on their animals for daily subsistence and livelihood (Cartin-Rojas, 2012). Livestock are raised for meat, milk, blood, hides and manure, as well as being economic assets. In countries like Ethiopia, cattle used as draught animals provide another intimate link with agriculture (Tschopp *et al*., 2010b). Livestock population growth in sub-Saharan Africa is projected to be 1.2% over the next few decades, with the main drivers being an increased demand for animal products, an increased economic status and achievement of food security (Thornton, 2010; Lunde and Lindtjorn, 2013). The rinderpest epidemic in the late 19th century illustrated how the extensive loss of livestock throughout Africa led to severe famines through direct loss of animal protein and loss of agricultural production due to scarce draught power.

Nevertheless, wildlife remains an important player in sub-Saharan Africa, for economic, including wildlife tourism, animal and human health, and conservation reasons.

For many African communities, wild-caught animals remain a major source of animal protein (Chardonnet *et al*., 2002; Timah *et al*., 2008). Live animals and wildlife meat (also known as bushmeat) are traded worldwide as a multibillion US dollar/year industry. For the most part, the international wildlife trade is illegal and thus uncontrolled, putting people, livestock and ecosystems at risk (Chomel *et al*., 2007; Karesh *et al*., 2007, 2012; Ogun *et al*., 2010; Smith *et al*., 2013). The estimated consumption and trade of bushmeat from Central Africa alone is over 1 billion kg/year, equivalent to an estimated 200 million animals (Wilkie and Carpenter, 1999; Karesh *et al*., 2012). A wide range of wildlife is hunted both legally and illegally, but in many places the African buffalo – a known reservoir for BTB – remains a favourite species for meat consumption due to taste and price (Ndibalema and Songorwa, 2008; Alexander *et al*., 2012). The public food safety concern originating from wildlife products not only includes bushmeat, but also legal wildlife exploitation. In Southern Africa, the wildlife meat industry is very active. Up to a quarter of all farmland in Namibia has been converted into commercial game farms (Turpie *et al*., cited in Magwedere *et al*., 2012). Namibia produces between 16,000 and 26,000 t of game meat for national and international markets (Lindsey, 2011), thus putting wildlife in an important niche for foodborne zoonosis (Magwedere *et al*., 2012). In Zimbabwe, game ranching is becoming more profitable than cattle ranching and game meat is often more expensive than beef (Chardonnet *et al*., 2002). In Zambia, there is rising concern about utilization of the lechwe antelope, an economically high-profile species in the country due to its BTB status, as it is estimated that around 80% of the hunted lechwe carcasses are BTB infected (Siamudaala *et al*., 2005; Malama *et al*., 2013). So far, no cases of BTB in humans originating from wildlife have been described in sub-Saharan Africa. However, this may reflect more a lack of disease assessment at the human–wildlife interface rather than true absence of BTB transmission. Hence, in sub-Saharan Africa, increasing exploitation of wildlife for human consumption will necessitate stricter meat examination protocols. There is likely a negligible risk of BTB transmission directly from wildlife to humans. However, it is possible that BTB may spill back from wildlife to cattle and affect cattle production (Meisinger, 1970; Cosivi *et al*., 1998). Future BTB control programmes may be an additional economic burden in these countries. For instance, the resurgence of BTB in UK cattle due to the uncontrolled reservoir in badgers cost the government £100 million/year (control, trade and market loss) (Matthews *et al*., 2006). In sub-Saharan Africa, a spillback scenario was recently described (Musoke *et al*., 2015).

Finally, existence of BTB in wildlife can have serious conservation consequences and impacts on a nation's wildlife-related tourism. The example of the BTB south–north spread through Krueger National Park (KNP), South Africa, starting in 1990 shows the extent of the problem if uncontrolled. BTB acquired from cattle in the southern part of the park spread among the buffalo population, which maintained the infection, and to at least 13 other spillover species, including lions which preyed on sick buffaloes. This puts the carnivore population, in particular, at risk (Michel *et al*., 2009; Maas *et al*., 2012; Bengis, 2012). BTB has also recently spread from KNP to neighbouring buffalo populations in Gonarezhou National Park in Zimbabwe (de Garine-Wichatitsky *et al*., 2013). This scenario highlights the threat of BTB in sub-Saharan Africa to tourism, biodiversity, viability of endangered species and the anticipated sustainable ecological and economic benefits of the Transfrontier National Parks initiative (Bengis, 2005).

Poorly Studied Livestock–Wildlife Interface

Although protected areas have been created to provide biodiversity protection, a large proportion of wildlife still lives outside these areas, particularly when the areas are unfenced (Prins and Grootenhuis, 2000; Mworia *et al*., 2008). Some species need a bigger territory than that provided by the national parks, and some species need to migrate regularly (Woodroffe *et al*., 2005). Humans encroach into protected habitats with their livestock in search of grazing areas and water, particularly during the drought season (Fig. 22.1), and in arid and semi-arid areas, wildlife share the same water points with pastoralist livestock (de Leeuw *et al*., 2001; Mizutani *et al*., 2005; Sitters *et al*., 2009). The contact interface is not restricted to protected areas and buffer zones but also exists in agriculture and rangeland.

Overall, the epidemiology and ecology at the BTB wildlife–livestock interface are still poorly known in terms of spatial and temporal livestock–wildlife relationships, animal behaviour and between-species dynamics, ecology and socioeconomic dynamics. We also do not know how pastoralists view all the factors influencing potential transmission of diseases, in general, and BTB, in particular. Risk factors for disease transmission between wildlife and livestock are rarely described in sub-Saharan Africa (de Garine-Wichatitsky *et al*., 2013).

Contact interface at water points

Rainfall and water shortages are the main drivers and constraining factors for the distribution and abundance of wildlife species and thus for contact opportunity between species (Gereta *et al*., 2004; Martin, 2005; Epaphras *et al*., 2008). Interaction between different wildlife species around natural and artificial water sources have been described (Valeix *et al*., 2007; Epaphras *et al*., 2008), but how wildlife and livestock interact is poorly recorded. Generally, wildlife tend to avoid livestock, but this is species specific and dependent on prevailing environmental conditions (de Leeuw *et al*., 2001; Zvidai *et al*., 2013). Negative associations in terms of animal displacement, between the presence of

Fig. 22.1. Swayne's hartebeest (*Alcelaphus buselaphus swaynei*) grazing with domestic cattle in Senkele Swayne's Hartebeest Sanctuary, Ethiopia. Photo courtesy of L. Siege.

livestock and the biodiversity and distribution of wildlife have been described (Prins, 2000). Herders tend to chase wildlife away from water points, so wildlife drink when human disturbance is at its lowest (Zvidzai *et al.*, 2013). Zvidzai *et al.* (2013) studied livestock–wildlife at water points located within Gonarezhou National Park (Zimbabwe), at the park boundaries and in the agricultural area. The authors concluded that BTB transmission was unlikely to occur through direct contact at the interface around water sources. However, intermediate species such as impala, kudu and warthog (*Phacochoerus africanus*), which are less affected by livestock presence (Prins, 2000; Zvidzai *et al.*, 2013), could play a role as disease transmitters by having close physical contact with BTB buffalo reactors, that stay within the park, and with livestock in the agricultural land outside the park.

Contact interface on grazing land

Common use of pastures is another potential risk for BTB transmission between wildlife and livestock. Mainly wildlife grazer species, as opposed to browser species, are likely to compete with cattle. There seems to be a species-specific tolerance level for cattle presence (Young *et al.*, 2005). Hartebeest and cattle compete directly for pasture in Kenya (Ego *et al.*, 2003) and Ethiopia (Tschopp, 2011, personal observation) (Fig. 22.2).

Lechwe and cattle are regularly seen grazing together in Zambia (Malama *et al.*, 2013). On the other hand, no mountain nyalas (*Tragelaphus buxtoni*), an endemic endangered species, have been observed in the Bale Mountain National Park (Ethiopia), when there is high livestock pressure (Stephens *et al.*, 2001).

Many grazer species favour grazing in old pastoral places, where grass cover is rich due to cattle manure (Reid *et al.*, 2004). As *M. bovis* can be excreted in cattle manure and survive in the environment for months (Tanner and Michel, 1999; Courtenay *et al.*, 2006; Jha *et al.*, 2007), it is notable that disease transmission can still occur even with a temporally asymmetric interface without direct animal contact.

Presence and abundance of wildlife species is also affected by vegetation cover (Mosugelo *et al.*, 2002).

Fig. 22.2. Human–livestock–wildlife interface in the Ethiopian Highlands. Photo courtesy of R. Tschopp.

If the latter is altered naturally or anthropogenetically, wild animals will move elsewhere (Hibert *et al.*, 2010), likely shifting the existing dynamics of the interface.

Added Value of a One Health Approach

Control of zoonoses in the domestic animal reservoir is likely to reduce human disease burden and is, in general, much cheaper than controlling the disease in the human population (Roth *et al.*, 2003; Knobel *et al.*, 2005). One Health approaches, including integrated study designs, integrated disease surveillance, integrated economic disease assessments, or integrated disease interventions including policy, often include only domestic animals and humans and rarely consider wildlife or, even less often, the ecosystem. However, as described above, livestock, human and wildlife health are as intimately linked to each other as they are to ecosystem ecology and health. Intervention strategies regarding BTB would therefore benefit from a synergy of two movements, One Health and ecohealth, that often work separately thus far. The One Health movement includes various sectors, but its main focus remains management of health risks to humans and animals (Zinsstag, 2012), whereas the more recent ecohealth movement approaches through ecosystem health, and its impact on human–animal health (Charron, 2012). Regarding BTB in particular, the One Health concept – although much discussed – is still weakly used in practice despite the lessons learned from the UK, New Zealand and KNP, as further described in the next section. In sub-Saharan Africa, information on the role of BTB in wildlife at the interface with people and livestock is still lacking. This reflects a low priority given to wildlife and lack of infrastructure (e.g. diagnostic laboratories), remoteness of sites, lack of a good diagnostic tests for wildlife, and cost and difficult logistics of testing wildlife in the field (e.g. cost of drugs, elaborate equipment, number of staff required) (de Garine-Wichatitsky *et al.*, 2013).

Without addressing these challenges, a One Health approach with inclusion of wildlife in its equation to control BTB will remain elusive for many countries. Important steps however, can be made in establishing a common One Health language and understanding of the concept amid all involved sectors (public health, veterinary health, wildlife sector and education). This will ultimately facilitate integration of resources, knowledge and efforts in order to reduce the risks to agriculture, conservation and public health.

Control of BTB

So far, BTB control in wildlife, similar to foot and mouth disease control in wildlife in Southern Africa, has included culling, fencing and animal-free corridors, as well as combinations of these or a ‘do nothing’ strategy (Caron *et al.*, 2003; Mysterud and Rolandsen, 2019). All approaches have drawbacks, ranging from inefficiency to interference with wildlife migration leading to decreased wildlife population and even mass mortality (Prins, 2000; Martin, 2005). In sub-Saharan Africa, BTB vaccination research in livestock (Ameni *et al.*, 2010) and in buffalo (de Klerk *et al.*, 2010) is ongoing but has shown variable success to date.

In New Zealand, brushtail possums are considered an exotic species/pest and are extirpated to control BTB (Nugent, 2011). However, African wildlife has an economic and environmental value and is an integral part of the African heritage, with many species now threatened or endangered and in need of protection. Wildlife auctions in South Africa reflect true economic value for wildlife (Chardonnet *et al.*, 2002). BTB is widespread among African wildlife and eradication is therefore impossible. This reinforces the importance of close collaboration between the agriculture and wildlife sectors to avoid spillover from domestic livestock into the naive wildlife populations, and spillback into the livestock population. The collaboration should not only include disease management but also habitat and land-use management, so wildlife and livestock can continue to coexist without posing a health threat to each other and community livelihoods continue to be secured.

Few cost analyses of BTB control options have been performed for the livestock sector (Bernues *et al.*, 1997; Tschopp *et al.*, 2012; Mwacalimba *et al.*, 2013). In Ethiopia, Tschopp *et al.* (2012) showed that there was neither loss of asset value, nor cost of disease due to BTB in rural and urban livestock systems. In Zambia, the cost of control was shown to outweigh the benefits from controlling BTB (Mwacalimba *et al.*, 2013). However, the results of both studies have to be seen purely from a monetary point of view. Quantification of benefits resulting from a BTB control programme is difficult, and its sectoral ramifications have so far not been studied in sub-Saharan Africa. This represents an important knowledge gap. An additional reason why this assessment must include wildlife is to assess cost-sharing schemes between the public health, livestock and wildlife sectors. This would include the economic value and return from wildlife. There is an urgent need for research at the contact interface throughout the continent, integrating epidemiology and habitat/species ecology, in particular to gain a better understanding of the interactions between species and the impacts of co-infections on BTB prevalence in wildlife (Caron *et al*., 2003; Maas *et al*., 2012; Beechler, 2013). The research must go beyond mere BTB prevalence studies.

Case study of BTB in Morocco

BTB is an endemic zoonosis in Morocco, with an estimated cattle individual prevalence of 18% (Srairi Mohamed Taher, 2011; Yahyaoui Azami *et al*., 2018). In 2017, human TB caused 3500 deaths in Morocco, with 36,000 new cases (WHO, 2017). However, no investigations have been performed to distinguish between human TB caused by *M. tuberculosis* and *M. bovis*.

Disease control interventions to reduce health and economic risks, such as those related to BTB, are non-linear processes. Although, statistical analyses of data have been used for many years to analyse different types of health interventions, mathematical modelling represents an alternative approach, which provides a broader understanding, especially regarding disease transmission to humans. Modelling approaches have been used, mainly for developing countries, to estimate different parameters and factors related to BTB. Previous publications on the economics of BTB focus mainly on the cost of disease and control efforts (Tschopp *et al*., 2012). Analyses of the profitability of control efforts are very scarce (Zinsstag *et al*. 2006). A simple compartmental deterministic mathematical model for BTB transmission in cattle and humans was established to provide a general understanding of BTB, with an emphasis on transmission to humans (Abakar *et al*., 2017). The cattle population was divided into three mutually exclusive compartments consisting of: (i) susceptible cattle (S_C); (ii) exposed cattle with latent BTB defined as positive to the tuberculin test without showing gross visible lesions (E_C); and (iii) infected cattle with active BTB showing TB lesions (I_C). The human population consists of four mutually exclusive compartments: (i) susceptible humans (S_H); (ii) exposed humans with latent BTB reacting to the Mantoux test (E_H); (iii) infected humans with active BTB (I_H); and (iv) humans recovered from BTB with temporary immunity (R_H). This is shown in Fig. 22.3.

Parameters and differential equations were used to model the dynamics of cattle and humans from one compartment to another. The parameters considered to model the different pathways were birth rate of cattle and humans, cattle-to-cattle and cattle-to-human transmission rate, mortality rate of cattle,

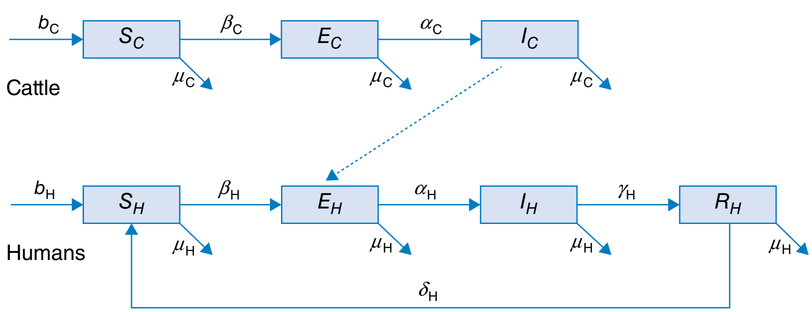

Fig. 22.3. Schematic diagram of the bovine tuberculosis (BTB) cattle–human transmission model for Morocco. S_C, susceptible cattle; E_C, exposed cattle with latent BTB defined as positive to the tuberculin test without showing gross visible lesions; I_C, infected cattle with active BTB showing TB lesions. S_H, susceptible humans; E_H, exposed humans with latent BTB reacting to the Mantoux test; I_H, infected humans with active BTB; R_H, humans recovered from BTB with temporary immunity. b_C, birth rate of cattle; β_C, cattle-to-cattle transmission rate; μ_C, mortality rate of cattle; α_C, inverse of cattle incubation period; b_H, birth rate of humans; β_H, cattle-to-human transmission rate; α_H, inverse of human incubation period; γ_H, treatment success rate of humans; μ_H, natural mortality rate for humans; σ_H, loss of immunity in humans. From Abakar *et al*. (2017), reproduced with permission.

natural mortality rate of humans, inverse of cattle and human incubation period, treatment success in humans and loss of immunity in humans. The parameters' values were estimated according to local data when available or extrapolated from international data when needed. A sensitivity analysis of the model recalculated the change of prevalence if individual parameters varied from baseline over 30 years.

Scenarios of test and slaughter were simulated to determine the effects of varying the proportion of tested animals (p) on the time to elimination of BTB (individual animal prevalence of less than one in 1000) in cattle and humans. The time to elimination ranged from 75 years for p = 20% to 12 years for p = 100%. For values of p > 60%, the time to elimination was below 20 years. The reproductive number decreased rapidly below one with an increasing proportion of test and slaughter p.

The cost of test and slaughter depends on the percentage p of animals tested and slaughtered. Lower p results in lower cumulated costs but longer time until elimination. The cumulated cost is remarkably stable for p values higher than 0.2, ranging between €1.47 to €1.87 billion within a time range of 12–75 years to reach freedom from disease. The model simulations also suggest that using a 2 mm cut off instead of a 4 mm cut off in the single intradermal comparative cervical tuberculin skin test (SICCT) would result in cheaper and quicker elimination programmes.

Using such mathematical models to investigate and analyse several disease control strategies scenarios, particularly for a neglected disease like BTB with a high cost control strategy, can be very insightful to inform policy makers for future programmes. However, future studies should include a wildlife component as well, since wildlife is a very critical element in BTB control, especially when very low prevalence levels are attained. Including wildlife compartments in the analysis will insure a long-term impact of the results of the models. In Morocco, BTB in wildlife is not deeply studied, but it has been reported in wild boars (El Mrini *et al.*, 2016).

Synergies and added values

The BTB example shows the important added value that an implementation of intersectoral collaboration between public health, the agricultural and the wildlife sectors would bring. However, it should also include the educational and sanitation sectors as well as ecologists, veterinarians and biologists. BTB directly impacts livestock health and thus indirectly public health and people's livelihoods. BTB also directly impacts biodiversity and wildlife conservation, hence the need for synergy between the One Health and ecohealth movements and conservation efforts. The information collected at the interface, reported and analysed, should be shared by the health, agriculture and wildlife ministries. Further added value can include sharing knowledge and expertise between the sectors, conducting common disease surveillance, and sharing laboratory facilities and transport.

Local communities, including pastoral communities, also have to be empowered and included in disease control strategies. Similarly, they must benefit from disease awareness programmes and socio-economic returns from wildlife (Sindiga, 1995; Kock *et al.*, 2002; Molyneux *et al.*, 2011; Homewood *et al.*, 2012). Most importantly, the theory of an integrated One Health approach to control BTB at the livestock–wildlife–human interface with inclusion of wildlife at planning, surveillance and intervention level needs to move from theory to practice and large-scale, long-term, evidence-based research conducted in Africa that would provide vital information on added value for all the sectors involved.

Future and Conclusions

The One Health approach in controlling BTB in sub-Saharan Africa is still in its infancy and has many gaps, in particular concerning wildlife. Human–livestock–wildlife interfaces are variable, fluid and dynamic in nature. They will continue to change as population growth continues and more natural resources are used. Further factors influencing the interface include climate change, intensification of animal husbandry and the different conservation choices made by countries (e.g. agricultural expansion versus wildlife conservation/tourism or game industry) (Bulte and Horan, 2003). All will influence the future interfaces and BTB transmission.

There is interdependence between people–livestock–wildlife and the environment that requires intersectoral collaboration in BTB control, so that it benefits livestock and wildlife-related economies, people's health and livelihoods, as well as biodiversity conservation. A merging of One Health and ecohealth approaches would likely strengthen any intervention strategies on BTB. Future research and development agenda should encompass the establishment of diagnostic capacity, ecological studies at the interfaces, the extension of cross-sectorial economic analysis, the development of locally adapted control strategies through participatory approaches, and further research on vaccine development.

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23 The Role of Companion Animals in Supporting Human Patients with Non-communicable Diseases

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Non-communicable Diseases

According to the World Health Organization (WHO) (2014a), non-communicable diseases (NCDs) kill more than 36 million people each year, with nearly 80% of the NCD deaths occurring in low- and middle-income countries. Further, four groups of diseases account for around 80% of all NCD deaths: (i) cardiovascular diseases, 17.3 million/year; (ii) cancers, 7.6 million; (iii) respiratory diseases, 4.2 million; and (iv) diabetes, 1.3 million. One risk factor in all four groups is physical inactivity, associated with about 3.2 million deaths annually (WHO, 2014a). Certain behaviours lead to four key metabolic/physiological changes that increase NCD risk: raised blood pressure, overweight/obesity, hyperglycaemia and hyperlipidaemia.

The numbers of young and older overweight people have increased at an alarming rate in recent years. Globally, *c.*35% of adults aged 20 and over were overweight in 2008; *c.*12% were obese by definition (WHO, 2014b). The mean body mass index (BMI) of the world's population increased dramatically between 1980 and 2008. According to the Global Health Observatory of the WHO at least 2.8 million people die each year as a result of being overweight or obese and *c.*35.8 million of global DALYs (disability adjusted life years, or lost 'healthy' life years) are caused by these problems (WHO, 2014b).

Depression is included in this chapter on NCDs and companion animals. Globally, some 350 million people of all ages suffer from depression, more women than men; it is the leading cause of disability worldwide (WHO, 2012a). Thus, it is a major contributor to the global burden of disease.

Companion Animals: More Than Just Companions

Many people consider the keeping of animals as companions, or pets, as status symbols of wealth and, in general, a useless by-product of affluent societies. This view, however, ignores the facts that: (i) at least for the two most common domesticated species of pets, dogs and cats, the animals first fulfilled utilitarian tasks; and (ii) that such animals are found in practically all cultures of the world, irrespective of economic status (Serpell, 1986).

Further, over the last three decades research has provided much evidence of the positive effects of animals, in particular dogs, cats and horses, on the health and well-being of people of all ages (McCardle *et al.*, 2011; Turner *et al.*, 2013; Fine, 2019). No doubt pets, especially exotic species, can be the source of zoonotic diseases; but a number of studies have now concluded that a healthy, immunized and parasite-free domestic animal can bring more health benefits to the owner, or patient, in the case of an animal-assisted intervention (AAI), than health risks (CALLISTO Strategy Report, 2013; Sterneberg *et al.*, 2016). Raina *et al.* (1999) further demonstrated that dog ownership was associated

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with decreased health-care costs in people over 65 years old living in their own homes, particularly during times of stress. The role that companion animals can (or might) play in combating a number of NCDs will be elucidated below. Practical examples from developing an AAI programme at a rehabilitation centre are provided before important aspects of working with animals are discussed and lessons learned over the years summarized.

Cardiovascular Disease

Friedmann and Thomas (1995) reported that both high social support by humans and, rather unexpectedly, pet ownership, predicted 1-year survival rates after hospitalization for acute myocardial infarction independently of physiological severity, demographic and other psychosocial factors. Dog owners were significantly less likely to die within 1 year than non-owners. Friedmann and Lockwood (1993) found the same result for non-dog pet owners versus non-pet owners. Friedmann *et al.* (2011) and Friedmann (2019) later summarized the physiological correlates of the health benefits from pets. Based on research on adults, the presence of companion animals is associated with reductions in chronic levels of physiological stress indicators and reductions in stress response to mild to moderate stressors. Although there are fewer studies on children, the conclusions are in the same direction. However, there have been no studies to date on the impact of companion animals on major stressors.

Early studies showed a reduction in systolic and diastolic blood pressure as well as heart rate while stroking a dog and a stronger effect if the study participants – all dog owners – were able to stroke their own animal as opposed to an unknown dog (Baun *et al.*, 1984). More importantly, pet ownership is associated with lower levels of accepted cardiovascular disease risk factors in men (and women over 40) such as high systolic blood pressure, plasma cholesterol and plasma triglyceride levels, whereas BMI, tobacco use and other potential factors were the same in the pet owners (n = 784) and non-owners (n = 4957) (Anderson *et al.*, 1992). However, the pet owners were more likely to be physically active. The American Heart Association concluded in a review that 'pet ownership, particularly dog ownership, may have some causal role in reducing CVD [cardiovascular disease] risk' (Levine *et al.*, 2013). A recent prospective nationwide cohort study with up to 12 years of follow-up found that dog ownership might be 'associated with a lower risk of cardiovascular disease in single-person households and lower mortality in the general population' (Mubanga *et al.*, 2017).

Obesity

Physical inactivity has been identified as the fourth leading risk factor for global mortality causing an estimated 3.2 million deaths a year (WHO, 2014c). The WHO concludes that regular, moderate-intensity physical activity – such as walking, cycling or participating in sports – has significant health benefits; it can reduce the risk of cardiovascular diseases, diabetes, colon and breast cancer and depression (WHO, 2014c). Interestingly, studies have shown that companion animals, especially dogs and cats, reduce the risk of cardiovascular diseases (Anderson *et al.*, 1992) and increase survival after myocardial infarction (Friedmann and Thomas, 1995), as well as reduce depression. Are the former related to dog walking? Although both dog and cat owners have significantly improved survival rates 1 year after a heart attack, usually only dog owners walk their animals. Indeed, in Anderson *et al.* (1992), pet owners reported qualitatively that they were walking more, and Serpell (1991) quantitatively demonstrated this during a 10-month prospective study of owners after acquiring a new pet. The WHO (2014d), in its Global Strategy on Diet, Physical Activity and Health, aims to reduce risk factors for chronic diseases that stem from unhealthy diets and physical inactivity through public health actions that are sustainable, comprehensive and actively engage all sectors. Owned dogs live many years and require daily movement outside of the home. Unsurprisingly, a number of studies presented at the recent triennial conferences of the International Association of Human-Animal Interaction Organizations (IAHAIO) (2014), as well as conferences jointly organized by the US National Institute of Child Health and Human Development (NICHD) and WALTHAM Petcare Science Institute in the UK, have investigated the link between dog ownership and physical exercise. The findings are summarized below.

In a population-based survey, Headey *et al.* (2008) found that among women residing in three Chinese cities, dog owners exercised for 20 min or 36% more often than non-owners, even while taking into account the effects of age, education, income and other health-related variables on walking behaviour.

Johnson *et al.* (2011) provide a comprehensive review of the health benefits of dog walking to people and their dogs. Findings from at least six studies indicate that dog owners are more physically active and more likely to meet the recommended level of physical activity than non-dog owners (Thorpe *et al.*, 2011). Because physical activity levels appear to be different for dog and cat owners, there might be differences in their respective health status. However, Turner and Gutzwiller (2004) found in Switzerland significantly lower expenditures for health and medication in cat-owning households than non-animal-owning households, as well as a tendency for such in dog-owning households, but no reduction in households with other pet species. Various potentially confounding variables were accounted for, such as overall income, household size and expenditures for the pets in this Swiss national random sample.

A further study called the OPET (Owners and Pets Exercising Together) assessed the metabolic benefits of 'walking the dog' and whether physical activity counselling for the dog provided by a speciality-care veterinarian impacts the metabolic status of owners and their dogs (Stephens *et al.*, 2011). The final results were published by Byers *et al.* (2014) and showed significant physiological improvements in the physical activity group counselled by the veterinarian.

Johnson and McKenney (2011) in their 'Walk a hound, lose a pound' community dog-walking programme matched behaviourally tested shelter dogs with non-dog-owning families. It is hypothesized that the dog may be a social lubricant for participants and their families to communicate while walking and afterwards. Further, dog walking may have the potential for improving long-term physical activity adherence through increasing readiness to engage in physical activity even beyond the dog walking (Johnson and Meadows, 2010). It has been shown that dogs motivate obese children to take physical activity (Wohlfahrt *et al.*, 2013).

Lastly, dog walking appears to be a catalyst for strengthening the social fabric of the community (Wood and Christian, 2011). Dog walking facilitated social interactions, social support and a sense of community, benefiting not only the dog walkers themselves, but also having a ripple effect into the broader community.

Under most circumstances, there are benefits to the dog from being walked. Canine obesity is widespread in dogs today in many high-income countries, with an estimated 44% of US dogs being overweight or obese (i.e. about 33 million dogs in the USA alone) (Stregowski, 2014). The main causes are improper diet and lack of sufficient exercise. The health risks of obesity in dogs are well known and similarly to humans include cardiac disease, hypertension, orthopaedic problems, various forms of cancer and diabetes. Preventing and managing weight problems in humans and their companion animals fit well within the realm of One Health.

Depression

By all accounts and sources, depression is on the increase in modern societies. According to the WHO at least 350 million people live with depression and it is the leading cause of disability worldwide: 'Depression is treatable, but most people with depression do not receive the care and support they need. … Lack of access to treatment and stigma associated with depression are major obstacles to people seeking help' (WHO, 2012b). Perhaps this is where companion animals can help – not in the sense of replacing classical therapies or medical treatment, but by providing additional support for the depressed person in the home setting. Several studies (Rieger and Turner, 1999; Turner and Rieger, 2001; Turner *et al.*, 2003) have demonstrated that both the presence of a cat in the private home, even more so interacting with it in the right moment, decreases negative mood-sets (fear, depression, introversion) significantly. This is explicable by changes in the cat's behaviour when close to a person in such a mood. It should not surprise us that many psychiatric clinics and psychotherapeutic practices maintain cats on their premises. However, the aforementioned studies were not conducted on clinically depressed persons, indicating a salutogenic effect of the presence of animals in the home setting. Psychiatrist Daniel Hell found that in human–human relationships the depressed person increasingly dissociates him/herself, the more (s)he feels misunderstood by the partner, who often attempts to help (Hell, 1994). The cat accepts the level of 'interactivity' the (depressed) owner wants to have and is present when the owner desires that contact without forcing itself on the human partner. Rieger and Turner (1999) found that the influence of a cat on human mood is similar to its behaviour: either neutral or positive, but not negative. To some degree, cats can be more pleasant partners for depressed people than humans can. This might make cats the better co-therapists than dogs for depressed patients (as dogs constantly seek contact and approval of their pack leader), but this remains to be tested directly.

There have been many studies purporting to examine the effects of dogs and cats on depression/depressed clients of psychotherapists, but many have been fraught with design problems and are inconclusive. A more rigorous study design with larger sample sizes would help. Nevertheless, Souter and Miller (2007) conducted a meta-analysis of the data in five very strictly controlled studies and found a significant positive effect of the animals, more importantly, an effect of moderate size on top of the other therapies still being applied to the depressive persons. Le Roux and Kemp (2009) later reported that visits with a companion dog once a week over 6 weeks to the elderly residents of a long-term care facility significantly reduced scores on the Beck Depression Inventory relative to those of the control group but not the anxiety levels.

Veterinarians with training in animal behaviour increasingly believe that dogs and cats can also suffer from depression ('believe', simply because they cannot be asked and 'only' show behaviour patterns similar to humans suffering from depression) (Eckstein, 2014; Veterinary Pet Insurance, 2014). A further indication that this is indeed the case is reduction of the symptoms after prescription of antidepressants usually developed for humans in the pet-appropriate dosage (Turner and Mertens, 2015; Schöning and Turner, 2018).

The effects of dogs and cats on clients and patients in psychotherapeutic practices and mental clinics, especially in promoting client communication, have been known for decades and are now widely acknowledged, though poorly researched (Levinson, 1962: Corson *et al*., 1975; Frick and Tanner-Frick, 2016). These are discussed in detail in the chapter on mental health (Hediger and Beetz, Chapter 26, this volume).

The Diagnostic Value of Companion Animals

Although both humans and their companion dogs and cats can suffer from diabetes as well as other NCDs such as various cancers and epilepsy, and research on these ailments in the one species can help the other, in this section we point out another role that companion dogs have taken on to assist their human partners: medical detection dogs. Medical detection dogs are usually divided into two broad categories, namely medical alert dogs and cancer and bio-detection dogs (Medical Detection Dogs, 2014). Dr Clair Guest in the UK is the pioneer in this field, which is rapidly expanding to other countries. Although some reports exist indicating a natural ability of dogs with their excellent olfactory sense to detect medical problems and change their behaviour in a way noticed by their owners, a number of programmes now exist to train dogs to reliably notify their owners of such problems (e.g. Canine Partners for Life, Canines 4 Hope, Epilepsy Foundation and Little Angels Service Dogs).[1]

One survey study indicated that behavioural reactions to hypoglycaemic episodes in owners with type I diabetes commonly occur in untrained dogs (Wells *et al*., 2008). Case reports indicating this ability have also been published in the medical literature (Chen *et al*., 2000; O'Connor *et al*., 2008). Dog-training programmes now exist to channel the dog's sensitivity and train specific reactions (e.g. fetching glucose tablets, barking near a comatose owner to gain attention of neighbours or pedestrians). However, the reliability of hypoglycaemia-alerting dogs remains to be tested.

Similarly, reports of (epileptic) seizure-alert dogs, capable of warning their owners of an oncoming seizure in time to take medication, appear in the popular literature but less often, or with mixed results, in the professional literature. An early report was quite promising (Strong *et al*., 1999). Dogs trained to alert their owners of an oncoming seizure were able to provide overt signals 15–45 min prior to a seizure and, in each case, the owner's seizure frequency reduced. Authors of a later study in the same journal stated that the success of such dogs depends largely on the handler's awareness and response to the dog's alerting behaviour (Dalziel *et al*., 2003). Two case reports found poor, misleading alerting behaviour within a clinical setting; in this case the setting was acknowledged to be part of the problem, at least for the dogs (Ortiz and Liporace, 2005). Finally, Brown and Goldstein (2011) suspect that such dogs can detect subtle behaviour changes, but might even be sensitive to heart rate or olfactory cues. Nevertheless, there is a need for rigorous studies to determine whether seizure prediction by such dogs is better than chance and what the false positive and negative prediction rates might be. A scoping review of some 28 studies, reduced to only five by the inclusion criteria, indicated that data were still too scarce and preliminary to reach any definitive conclusions regarding the success of seizure-alert dogs and associated questions (Catala *et al*., 2018).

There is a fair amount of good evidence for the detection of various cancers by trained 'medical detection dogs'. In most cases the tests utilize the extreme sensitivity of the dog's olfactory ability after an initial training period. On average, the dog is able to detect, for example, a small concentration of butyric acid (10,000 molecules/cm^3 air), whereas humans require a concentration a million times higher for initial detection (Feddersen-Petersen, 1986). Probably there is a release of volatile chemicals by the cancerous cells either on the skin surface or into the blood and urine of afflicted persons. With respect to melanoma detection, in an early experimental test with two dogs, the animals demonstrated reliable localization of melanoma tissue samples hidden on the skin of healthy volunteers (Pickel *et al*., 2004). Willis *et al*. (2004) concluded that dogs can be trained to distinguish patients with bladder cancer based on urine odour alone more successfully than expected by chance, also suggesting the presence of tumour-related volatile compounds in the urine.

McCulloch *et al*. (2006) examined the accuracy of canine scent detection in early- and late-stage lung and breast cancers. A food-reward-based training method was employed on five household dogs to distinguish by scent alone exhaled breath samples of 55 lung and 31 breast cancer patients from those of 83 healthy controls. The dogs were taught to sit/lie in front of positive samples upon detection; a correct response to the control samples was to ignore them. The dog handlers and experimental observers were blinded to the identity of the breath samples. Concerning the lung cancer patients and controls, overall sensitivity of canine scent detection compared to biopsy-confirmed conventional diagnosis was 0.99 and overall specificity 0.99. For the breast cancer patients and controls, sensitivity was 0.88 and specificity 0.98. Sensitivity and specificity remained similar across all four stages of both diseases. The authors concluded that the dog training was efficient and cancer identification of exhaled breath samples was accurate.

Ovarian carcinomas have been detected by a trained dog in double-blind tests with 100% sensitivity and 97.5% specificity (Horvath *et al*., 2008). Colorectal cancer screening with odour material (exhaled breath and watery stool samples) by one trained Labrador retriever yielded a sensitivity of canine scent detection of breath samples compared with conventional colonoscopy diagnosis of 0.91 with a specificity of 0.99 (Sonoda *et al*., 2011). Sensitivity of detection of the stool samples was 0.97 with a specificity of 0.99. Olfactory detection of human bladder cancer by dogs trained to distinguish patients with this ailment on the basis of urine odour was more successful than expected by chance alone, although taken as a group, the dogs had a mean success rate of (only) 41% (Willis *et al*., 2004).

Although biopsy results will remain paramount for the definitive diagnosis of various forms of cancer, we might expect that dogs prove beneficial for earlier detection, either indirectly by changes in their behaviour towards their owners (once the owners become aware of their sniffing abilities), or in early screening programmes. If the latter prove financially advantageous, this would be a further benefit.

In conclusion, these discussions are summarized well with a fitting citation from an editorial by McCulloch *et al*. (2012) on lung cancer detection by canine scent:

> In both the literal and the metaphorical sense, with the publication of these papers on canine scent detection of lung cancer, dogs are once again demonstrating their ability to serve as protectors and guides. People worldwide feel a close affinity with the dog as a friend and protector. Whether or not sniffer dogs actually make it into the continuum of diagnostic evaluation has yet to be seen; their image could be employed in public health outreach for cancer screening, and may encourage people with worrisome symptoms to take earlier action. This would be a case of the dog acting as a shepherd; Lassie and Rin Tin Tin are still out there looking out for our health.
>
> McCulloch *et al*. (2012, p. 512)

Practical Examples from a Rehabilitation Centre

Animal-assisted therapy (AAT) as a form of AAI is a growing approach in neurorehabilitation. In 2013, this form of intervention was introduced at REHAB Basel, which has now become one of the leading projects of AAT in Switzerland. Besides the development of concepts for working with animals for the inpatients of this clinic, there has been a large research project investigating effects of AAT for patients with acquired brain injury.

Since starting an AAT programme in a hospital and rehabilitation clinic such as REHAB Basel is often accompanied with obstacles and prejudices, we combined this with an investigation of staff members' attitudes about AAT before and after implementation (Hediger and Hund-Georgiadis, 2017). The expectations and concerns of the entire staff of the clinic were assessed using a questionnaire before implementation of the programme, as well as 1 year after the start of the programme. At the second time point, actual experiences were measured using the same questions. Results revealed that 91% of the staff had positive expectations before the start of the AAT programme. However, 30% of the staff members anticipated problems with hygiene and 38% anticipated injuries. These concerns significantly dropped after 1 year of experience. The positive attitudes, however, remained stable in the context of practical experiences. Moreover, staff members were positively influenced by the presence of the animals and reported seeing the animals as enriching their job (Hediger and Hund-Georgiadis, 2017). This shows that even if there are concerns before implementing AAT in health-care settings, staff members have high acceptance and actual experiences were more positive than their expectations. This case example shows that if good protocols are in place, AAT can provide added value not just for patients but also for staff members and visitors to a clinic.

Working in neurorehabilitation, and especially with patients with acquired brain injury, means searching for learning possibilities for each individual patient, ranging from patients in a vegetative state to patients that are being reintegrated into everyday life and their jobs. Effective learning needs therapeutic situations that evoke motivation and interest in the patients and adapted information in a way that it can be processed by the patients. REHAB Basel offers a wide range of therapeutic interventions to provide a holistic rehabilitation that aims at the highest possible quality of life and independence of the individual patient. AAT is one approach to do so since working with animals offers a broad range of everyday-life-like tasks and experiences and often elicits high motivation in patients. The clinic has built a therapy animal garden, housing over 40 animals of different species: horses, a mule, sheep, goats, miniature pigs, chickens, birds, rabbits, guinea pigs, cats and visiting dogs. Employed animal keepers guarantee the appropriate care for and training of the animals and assist the therapists during the sessions if needed. The speech, occupational, physio- and psychotherapists can plan their sessions with or without an animal, according to patient needs and rehabilitation goals. However, if a therapist wants to perform AAT, this needs to be prescribed by the physicians and is documented in the same way as all therapeutic sessions. To ensure high quality, the AAT session is conducted together with a professional in AAT.

The different species and also the different characters of the individual animals offer different possibilities of integrating them into a therapy session. The choice of the animal and the activity is based on the rehabilitation goal set by the therapist and the patient (Hediger, 2019). Patients in a vegetative state or in a minimally conscious state lying in bed can be visited in the clinic by a qualified visiting dog where the contact with the animal often leads to emotional reactions, self-initiated activities and an adaption of the muscle tone and breathing. If patients are in a later rehabilitation phase, a chicken can provide opportunities in a speech therapy session to talk about what patients observe or experience or how food for this chicken can be prepared. Alternatively, patients can plan, arrange and move around markers on the ground with a mini pig in a physiotherapy session that not only requires different movements but also spatial/space orientation, coordination and persistence. Based on our experiences, animals can be very helpful for patients that are not motivated for therapy because they offer a relationship and because caring for another living being is a deep human need making tasks in therapy associated with the animal highly meaningful.

Most of the studies investigating AAT in neurorehabilitation focus on the effects of horses and hippotherapy (Munoz Lasa *et al.*, 2015) and there is almost no research on patients with acquired brain injury. However, preliminary results are promising. For example, dog-assisted speech-language therapy led to more motivation and joy as well as less stress in patients with aphasia compared with traditional speech-language therapy while both were effective therapeutically (Macauley, 2006). In another study, the gait pattern and walking speed of patients with hemiparesis after a stroke improved during dog walking compared with walking with a cane (Rondeau *et al.*, 2010). In a first randomized controlled trial, patients with acquired brain injury displayed significantly increased social behaviour and positive emotions when they interacted with an animal during therapy compared with standard therapy sessions (Hediger *et al.*, 2019a). Moreover, these patients had higher scores in concentration and alertness as rated by themselves and the therapists, while they displayed more instances of distraction during AAT sessions than in standard therapy sessions (Gocheva *et al.*, 2018).

Albeit we have promising reports from practice, research on AAT with patients with disorders of consciousness is even more scarce. Zieger (2011) documented that 13 patients with disorders of consciousness showed significant improvements in visual exploration behaviour, spontaneous reactions, and target-oriented movements after 6–15 weeks of dog-assisted therapy. Similar results were described in a case study with a patient in a persistent vegetative state who received long-term treatment of canine-assisted therapy (Bardl *et al.*, 2013). At REHAB Basel, we conducted the first controlled trial and found that patients in a minimally conscious state showed more behavioural reactions such as increased eye and physical movements and increased physiological arousal measured via heart rate variability during AAT compared with control sessions. We interpret this as a sign of increased consciousness during therapeutic sessions in the presence of an animal (Hediger *et al.*, 2019b).

Practical Aspects of Working in AAI with Animals

Past experience from early attempts to found AAI programmes by individuals or groups which have either failed or faced tremendous difficulties have taught us how to avoid these situations. Every programme in AAI, whether it belongs to a social institution, or is offered by an outside association or a private individual, should have the following characteristics: (i) a governing body and director who is in charge; (ii) a mission statement, specific and announced goals; and (iii) an operating budget and budget control. If the programme is large with more than one or two service providers, then it also needs a programme coordinator and supervisor, a method to inform all of the providers on a regular basis, and a continuing education plan for the providers. Both large and small programmes (with just one provider) need to have a policy and solution ready for all contingencies (e.g. illness of one of the animals or the provider; maltreatment of one of the animals; an accident caused by an animal or a client), a procedure for documentation of case reports, session scheduling and histories, veterinary records, etc., and proper insurance coverage. All providers must also be aware of client/patient rights, the importance of confidentiality and of relevant laws and ordinances (e.g. health and hygiene, animal protection and welfare). Many programmes have a designated veterinarian for advice, consultations, immunizations and emergency care (sometimes on the board of the programme), a medical doctor and/or an education specialist on their advisory boards, depending on the mission and goals of the programme.

Working with companion and even farm animals to help patients and clients with health problems has become very popular. However, this popularity potentially brings with it inherent dangers for both the recipients and the animals involved if: (i) improperly trained or unqualified persons are providing the services; and/or (ii) there is poor selection and/or preparation of the animals and lack of protective involvement. Two well-established organizations, the IAHAIO[2] and the International Society for Animal Assisted Therapy (ISAAT)[3] have taken the lead to ensure that these dangers are minimized.

An international IAHAIO commission, chaired by Jegatheesan (2014, 2018), formulated and agreed to the definitions of AAI, which include but distinguish between AAT, animal-assisted education or pedagogy (AAE), animal-assisted coaching/counselling (AAC) and animal-assisted activity (AAA). In each subdiscipline the providers must be formally trained (with active licensure, degree or the equivalent) and have adequate knowledge about the behaviour, needs, health and indicators and regulation of stress of the animals involved. Essentially, they work within their own professional disciplines but are especially qualified to employ animals in their work. It is important that the administrators and staff of social institutions know and respect the differences between these subdisciplines and use the correct terminology. Quite often a hospital or clinic will state that they offer AAT, when in fact, the visits by animal owners with their charges are AAAs. This is not meant to diminish the value of such visits for motivational, educational or recreational purposes, but they are not necessarily AAT; these providers must also have received at least introductory training and their animals must be well prepared for such visits.

How can the administrator of a social institution determine whether a potential provider is qualified to conduct AAI? Along with requiring evidence of basic education and further training in a profession and reference letters from previous employers, they must provide proof of continuing education in AAI. There are major differences in quality – with some being distance or online courses with no practical training. It is recommended that proof should come from a programme accredited by the ISAAT, which has the highest standards worldwide. There is no equivalent accrediting body for AAI continuing education programmes in North America or elsewhere. The independent ISAAT accreditation board consists of well-known experts in their own fields of practice and education. The board must assure that the ISAAT standards are met concerning: (i) the admission requirements to the programme after basic training (at the bachelors level in various fields); (ii) the interdisciplinary nature of the theoretical topics covered; (iii) the total number of hours required; (iv) the qualifications of the teaching staff; (v) the number of practical hours required (internship, job shadowing); (vi) a thesis (final project report); and (vii) examination regulations.

Regarding the care and welfare of the animals involved, IAHAIO covered general aspects in a White Paper (Jegatheesan, 2014, 2018; see IAHAIO, 2014) to which ISAAT also adheres, but the latter organization went even further in its 'ISAAT Species List 2018' (ISAAT, 2018). Both organizations prohibit employing non-domesticated and unprepared (non-socialized, non-habituated, unconditioned) species/animals for direct contact with people, or animals requiring special permits for housing or handling. ISAAT has listed those species considered domesticated in 2018 and recommends employing currently endemic over exotic species for conservation reasons. Non-domesticated, wild animals in their natural habitats and such animals in zoos and centres for rehabilitation purposes, which follow international zoo animal welfare standards, may only be observed in animal-assisted programmes without any interventional contact. The animals involved in AAI programmes should be specially selected for the work they are to do, be healthy, not dangerous and fulfil the criteria of risk management (these being: reliable, controllable, predictable and appropriate) (Delta Society, 1992). This might be why both dogs and horses are most frequently involved in AAIs.

Unfortunately, there is little research to guide providers on how often and for how long they can involve their animals in interventions before providing a break to avoid stress. Research investigating these questions is still rare and has mostly been done in dogs and horses (Haubenhofer *et al.*, 2005; Mills *et al.*, 2014; De Santis *et al.*, 2017; Glenk, 2017; Gut *et al.*, 2018). Research that has been conducted does not speak against using animals for this work. Opinions on the allowable frequency and duration of sessions to protect the animal vary greatly, probably also due to individual tolerance differences between the animals. Presently it is more expedient to train the providers (animal owners) about the stress signals their animal species can show, which ISAAT programmes indeed do, and to consider the fact that the owners probably know their individual animals best.

Many AAI providers are employed by institutions either full- or part-time in their original profession (e.g. as a social worker, special education pedagogue, speech or physiotherapist) and are allowed – or encouraged – to conduct AAIs after completion of continuing education in that field within their work as that professional. Occasionally the employer supports the financial burden of such training. Other AAI providers with private practices offer their services to individual clients who can afford them, or have good connections with foundations offering such financial support to those who cannot. Financial issues and budgeting need careful consideration before beginning to work in this field. A survey of the members of the Swiss society for AAT and activities (Gesellschaft für Tiergestützte Therapie und Aktivitäten (GTTA)) in 2018 found that the *annual* costs for the animals involved – part of the purchase cost, daily animal care and housing, food, veterinary costs – averaged CHF12,000 (equivalent to US dollars). After the cost of their basic professional training, these providers also had to cover the expense of their continuing education in AAI, running between CHF5000 and CHF10,000 per course. They were able to charge clients between CHF75 and CHF193, or an average of CHF115 per 60-min session (see the brochure *Tiere können helfen – wenn professionall engesetzt und erlaubt*, GTTA, n.d.). From this, it is quite clear that one will not become rich in the field of AAI, but the satisfaction of helping clients overcome or cope with health problems is sufficient motivation for most of the providers.

Nevertheless, it should not be a surprise, given all of the above information, that the mid- and long-range goals of the professional AAI societies in Europe and elsewhere include:

- the elimination of administrative barriers that prohibit the presence and use of healthy, well-trained and well-selected animals in public social institutions to benefit patients/clients there; and
- coverage of at least part of the treatment costs of patients should be provided by health insurance policies (or supplemental insurance) when conducted by trained and recognized AAI specialists.

Lessons Learned

This chapter demonstrates that companion animals are more than just companions, and that they contribute significantly towards our health in one way or the other. The human–animal relationship is in fact an ideal topic to illustrate the added value that the One Health concept has to offer (IEMT-Switzerland, 2014). Not only is public health affected, but also increasingly, the health of individually challenged persons through AAIs, which is the focus of a number of international organizations today (IAHAIO, 2014; ISAAT, 2018). But only when we look after the health and welfare of those companion animals can we expect to benefit from their company – either in the private setting, in special settings such as hospitals, rehabilitation centres and schools, or in public society. That is truly One Health.

In particular, and especially for therapy-resistant patients and clients, AAI opens new possibilities for treating persons with coronary heart disease, depression, acquired brain injury, and – because of its motivating effect – even obesity, while the diagnostic abilities, especially of dogs, are proven and need to be more often utilized for early diagnosis and to alert owners of impending situations.

There is also growing evidence of cost efficiency, so health insurance companies should consider covering treatment costs in the future, when provided by qualified persons with animals that meet specific standards.

Notes

[1] Programmes to train dogs to reliably notify their owners of medical problems are as follows.

Canine Partners for Life. Available at: https://k94life.org/ (accessed 11 June 2020).

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24 Towards Resilience: the One Health Approach in Disasters

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One Health Dimensions of Disasters

Disasters are not a new phenomenon. The human race has had to face disasters throughout its existence and this reality carries through to the modern day. The number of natural disasters worldwide in the last 50 years, however, has more than quadrupled, creating an even greater sense of urgency to ensure our preparedness, mitigation, response and resilience to them (EM-DAT, 2019). In 2018 alone, there were '315 natural disaster events recorded worldwide with 11,804 deaths, over 68 million people affected, and USD 131.7 billion in economic losses.' (CRED, 2019, p. 2). What's more, disaster events are expected to increase in severity and frequency given planetary weather extremes from climatic changes, and human population growth, urbanization and industrialization (Siri *et al.*, 2016; Watts *et al.*, 2019). Disasters may strike unpredictably and are indiscriminate in which populations of people and animals are affected. The scale of predictability varies widely among these events. Some natural disasters are highly forecasted, for example a hurricane that can be tracked for days with its landfall closely approximated. Others, like earthquakes, may not be as predictable. Human-made disasters can be true surprises or predictable surprises; the latter describes disasters that should have been anticipated and avoided or minimized (Watkins and Bazerman, 2003). There is also a high degree of uncertainty with disasters regarding impact to the built and natural environment, as these impacts are never fully projected. This holds true for loss of human and animal life estimations and how communities and individuals will ultimately react to the often overwhelming loss and change that accompanies these events. Disasters are increasingly impacting the most vulnerable populations in global society and hampering efforts to improve health and standards of living (Phibbs *et al.*, 2018). While vulnerability is most often applied to human populations in given locations (social vulnerability), the concept is directly relatable to the existing animal populations and ecosystems corresponding to those areas. If society is to appropriately respond and ideally adapt to climatic and anthropogenic changes to the planet, including disasters, it is crucial these challenges are approached through the application of One Health.

What is a disaster?

According to the United Nations Office for Disaster Risk Reduction (UNDRR), a disaster is:

> A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses

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and impacts … The effect may test or exceed the capacity of a community or society to cope using its own resources.

(UNDRR, 2017a, webpage)

Thus, there are profound and often crippling effects from disasters and affected local populations lack the capacity and/or the capability to effectively deal with them. The dynamic and complex interdependence of people, animals and the environment, and how they are collectively impacted by these adverse events, underscores the need for a One Health approach to disasters.

The International Federation of Red Cross and Red Crescent Societies (IFRC) frames the complexity of disasters with a disaster equation (see Fig. 24.1; IFRC, 2019a). It abandons older reasoning whereby emergency managers and disaster scientists focused primarily on hazards and the risk or danger of an event occurring from that specified hazard. The IFRC's equation demonstrates that a disaster is the product not only of the presence of a hazard but also the vulnerability of individuals or populations to the effects of the hazard, and their capacity to cope with and recover from those effects. Therefore modern conceptualization of disasters goes beyond hazard recognition (and associated risk), and instead aims for broader risk reduction and increased resilience of individuals and communities.

Risk reduction is a concept that directs an individual, community or population to anticipate, cope with and recover from disasters by reducing exposure to existing hazards, and avoid creating new risk. Vulnerability, closely linked to risk, is highly influenced by individual traits and experiences, as well as socio-economic, political, cultural and geographic factors. An increasing global population, with the majority living in poverty in urban disaster-prone areas with inadequate medical and public health infrastructure, increases the amount of people vulnerable to disasters (Kouadio *et al.*, 2012; Smith *et al.*, 2018). The IFRC's equation takes into account the capacity of a population and government to deal with hazards. Coping capacity is dependent on the availability of resources that can be used to handle an event, including personnel, supplies, services and funds. The IFRC's equation makes clear that comprehensive disaster management must focus on risk and vulnerability reduction along with the promotion of coping capacity in order to minimize disaster impact and severity. The future approach to disasters is one that values and utilizes the inclusive and multisectoral attributes gained from One Health to act early and purposefully to mitigate these impactful events.

$$\frac{\text{VULNERABILITY + HAZARD}}{\text{CAPACITY}} = \text{DISASTER}$$

Fig. 24.1. Disaster equation. Adapted from the International Federation of Red Cross and Red Crescent Societies (IFRC), 2019a.

Major emphasis should be placed on building resilience to disasters. The UNDRR defines resilience as:

> The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.
>
> (UNDRR, 2017b, webpage)

The definition recognizes the need to not just survive disastrous events, but spring back from them with reduced losses. In order to be successful in achieving this outcome, resilience thinking and actions need to be engineered into individuals, communities and organizations (all of society) and integrated across all physical and ecological systems. This is a lofty goal, but one in which all types of societies should invest. Building the culture and practice of resilience to disasters necessitates resolve and cooperation among all stakeholders who share responsibility for the reciprocal health and well-being of humans, animals and the environment.

Disaster characterization

Disasters have historically been characterized based on parameters such as cause, onset, frequency and impact. The cause of a disaster can be found in natural hazards (geophysical, meteorological, hydrological or climatological, like hurricanes and earthquakes), biological phenomena (infectious disease), or anthropogenic hazards (including human activities such as technologic or industrial incidents) (IFRC, 2019b). Anthropogenic hazards can lead to what is commonly termed 'man-made disasters', which include examples such as chemical spills, environmental degradation, nuclear accidents and explosions, such as the Deepwater Horizon oil rig explosion in 2010 (Barron, 2012). These events can be unintentional and represent unfortunate accidents, or they can be the result of intentional human behaviour demonstrated by calculated and willful acts of terrorism, to include bio- and agroterrorism. A disaster's onset is variable and can be slow and insidious, like a drought or sea-level rise, or a sudden event, like an earthquake or volcanic eruption. Disasters can be classified according to their frequency. Disasters can be: (i) frequent and expected to occur at certain intervals, like hurricanes; (ii) infrequent, such as the 100-year storm predictions; or (iii) of unknown frequency, such as for wildfires. The frequency of these variables is dependent upon an area's geographic location, climate (and changes thereof), and human and animal interaction with the hazards.

Lastly, disasters can be described by their impacts. They can be typed as small scale and large scale; the former indicating an event that impacts a local community(s) and requires assistance beyond the impacted community, whereas the latter happens on a grander scope and calls for national or international support (UNDRR, 2017a). The post-disaster impacts on communities, animals and the environment occur on a continuum from the immediate, short-term to longer-lasting or delayed effects and vary widely in their severity. Immediate effects could include illness and death in people and animals resulting from physical and emotional trauma, and sheer physical destruction of infrastructure and natural habitats (Noji, 2000; Paterson *et al.*, 2018). Longer-lasting and more indirect effects include, but are not limited to: (i) continued or delayed-onset illness and death from exposure to hazardous materials; (ii) dense living conditions; (iii) medical and public health breakdowns; (iv) population displacement; (v) contaminated ecosystems; (vi) destroyed or disrupted industries and economies; and (vii) food insecurity (Young *et al.*, 2004). Furthermore, there are pre-existing conditions that will compound the severity and complexity of disasters in regard to how it affects the community, animal populations and the environment. Referred to as aggravating factors, they include poverty, population density, unplanned urbanization, environmental degradation and war and civil strife (IFRC, 2019c). Importantly, a community that has been affected by a disaster will have these conditions exacerbated with sometimes insurmountable consequences. Listed by the World Bank as one of the poorest countries, the Pacific island nation Vanuatu is an example of this phenomenon (World Bank, 2019). In 2015, Vanuatu was struck by Tropical Cyclone Pam, a category 5 cyclone that caused unprecedented damage totalling US$447.1 million, representing approximately 64% of the nation's gross domestic product (GDP) (Rahman, 2016). Vanuatu continues to be challenged as a consequence of this disaster and accepts international monetary aid to assist its recovery.

Need for a One Health approach to disasters and building resilience

One Health disaster management is a comprehensive, systems thinking approach that incorporates human, animal and environmental considerations into each of the continuous and overlapping disaster management phases of mitigation, preparedness, response and recovery. The involvement of people, animals and the environment is common to all disasters and this fact alone necessitates the call for a One Health approach to disasters. The One Health philosophy has been applied to many global socio-ecological problems from antibiotic resistance (see also Szelecsenyi *et al.*, Chapter 18, this volume) and biodiversity loss to zoonotic disease, so its application to disasters is appropriate and timely. Preparing for and responding to disasters requires an inclusive and collaborative effort across public and private sectors. These include government, first responders (police and fire), public health, medical and veterinary health professionals, academia, environmental experts, agriculture, the military, industry, non-governmental organizations (NGOs) and the communities themselves. Prior to any disaster event these stakeholders should all be integrated into joint planning, training and exercising in the introductory phases of emergency management, namely, mitigation and preparedness. This will help ensure sustainable collective cooperation. Involvement of the various sectors in response and recovery phases vary depending on the nature and severity of the disaster and specific needs caused by the event, but are cemented by prior engagement of stakeholders.

A One Health approach to disasters ensures the consideration and response to the human, animal and environmental impacts of a disaster. There is much to be said for how efforts to assist and protect animals in disasters yield rewards in health and wellness for both animals and humans and prevent secondary environmental effects. The intimate connection between people and animals, often referred to as the human–animal bond, has received much attention in recent disasters and highlights the need for experts to consider animals in disasters. People will fail to evacuate without their animals (Heath *et al*., 2001) or will attempt re-entry into evacuation/disaster zones to save their pets or livestock (Hall *et al*., 2004). Failing to account for these situations runs the risk of injury or loss of human and animal life and puts rescuers at additional unnecessary risk; both of which represent poignant lessons learned in Hurricane Katrina in Florida and Louisiana (USA) in 2005.

Animals play many roles in disasters and their involvement has animal welfare, public health and safety, economic and human mental health implications. In addition to the emotional and psychological impacts, animals must be considered in disasters for several other reasons. First, is their potential to transmit zoonotic disease. During the response to Hurricane Maria in Puerto Rico in 2017, rabies and leptospirosis were significant concerns and, in the case of leptospirosis, caused additional morbidity and mortality and cost to the rescue efforts (ProMED-mail, 2017; Concepción-Acevedo *et al*., 2018). Secondly, animal bites or other injuries from domestic, stray and wild species are a concern after disasters. People who contact animals during a disaster are at risk of harmful interactions as animals are displaced and under undue stress. This is also true for responders as they work to rescue animals (Warner, 2010). In addition, these displaced animals can cause road accidents because animals are no longer in typical confinements due to the destruction of buildings and fences. A One Health approach to disaster management is critical to ensure food safety and food security in several ways. Disasters can expose food animals to contaminated water, feed and air. Displaced and unrestrained animals can contaminate surface water with faecal material. If sufficient animals are killed in a disaster (in some cases, only a few), it may threaten a community's or even a country's food security. A One Health approach is also important for the positive way animals are involved in disaster response. Animals such as dogs and horses are often involved in life-saving search and rescue operations and animals may also serve as sentinels to signal impending human disease from a natural or bioterrorism cause. Companion animals are known to positively contribute to the mental health, coping and recovery of people following disasters.

Disasters release natural and hazardous contaminants into the environment which alter and pollute ecosystems (Young *et al*., 2004). These tangible threats can adversely impact human and animal health and disrupt and harm ecosystem services. History has demonstrated that hazardous material releases have negatively impacted large geographic areas and many people (Young *et al*., 2004). The involvement and value of environmental experts to One Health preparedness and response to disasters cannot be underestimated. Environmental professionals can assist with assessments and work related to: (i) potable water, water quality and floodwater defence and control; (ii) disposal of sewage and wastewater; (iii) solid waste and debris removal and management; (iv) air quality; (v) agriculture and food safety; and (vi) vector control. All of the above are immediate and long-term environmental problems that need to be addressed in the aftermath of a disaster.

The contemporary approach to disasters adopts the concept of disaster risk reduction (DRR). According to the UNDRR, DRR aims at 'preventing the creation of disaster risk, the reduction of existing risk and the strengthening of economic, social, health and environmental resilience' (UNDRR, 2017c). The Sendai Framework for DRR 2015–2030 is supported by the UNDRR and aims to reduce existing risk and strengthen resilience to disasters through an 'all-of-society' and 'all-of-state institutions' engagement and participation (UN, 2019). While it is not called a One Health approach, it encompasses the multidisciplinary, multisectoral inclusive approach to disasters and encourages governments to involve all stakeholders – especially those community members who are embedded and directly affected. A shift from agency to a One Health community-centred focus capable of identifying existing hazards and specific societal vulnerabilities is crucial to improve mitigation and response to disasters.

Critical Goals in One Health Disaster Management

The incorporation of a One Health approach to disaster management will reduce the existing siloed approach and allow for planning and mitigation towards secondary and tertiary effects of disasters. When stakeholders from the three elements of One Health work together, it leads to a comprehensive mitigation strategy and plan. In potential public health emergencies of international concern, 70% of emerging infectious diseases fall within the animal–human interface (WHO, 2004; Jones *et al.*, 2008). Working collectively will allow the response and recovery phase to be more cohesive, efficient and effective.

Disaster management agencies and departments should include stakeholders from the three One Health perspectives to ensure hazards and issues are carefully examined. The specific stakeholders will vary depending on the local hazards. Together with traditional humanitarian first responders, a One Health approach should include: (i) veterinarians; (ii) animal rescuers and other non-profit-making individuals/organizations; (iii) state Disaster Animal Response Team (DART) representatives; (iv) agriculture (animal and crop) and/or aquaculture representatives; (v) local land trust representatives; (vi) conservation experts; (vii) indigenious population representatives; and (viii) other government agencies such as the Environmental Protection Agency and local Department of the Interior representatives (in the USA), animal control officers, and many others. These stakeholders know the primary, secondary and tertiary effects of a disaster in their sector and inclusion of those perspectives in all disaster management phases will allow potential issues to be identified and either mitigated or planned for (Schneider *et al.*, 2011).

The disaster management cycle

Figure 24.2 illustrates the disaster management cycle. The objective and goals of One Health in the mitigation phase of disaster management includes activities meant to prevent or reduce (mitigate) hazards and their impacts and primary consequences while also attempting to reduce the risk of unintended consequences and second- and third-order effects. The mitigation phase is an all-hazards approach to reducing the impact of a disaster. According to the US Federal Emergency Management Agency (FEMA):

> Mitigation is the effort to reduce loss of life and property by lessening the impact of disasters. In order for mitigation to be effective we need to take action now – before the next disaster – to reduce human and financial consequences later (analyzing risk, reducing risk, and insuring against risk).
>
> (FEMA, 2019)

Fig. 24.2. The four phases of the disaster management cycle.

The human impact cannot be the only reason to take action, nor is the human risk the only risk to consider. All disasters impact human, animal and environmental health, but the impact to animal health also directly impacts human and environmental health, just as environmental health also directly and indirectly impacts human and animal health. These secondary and tertiary effects can be as devastating, if not more so, than the primary effects of the disaster (Fig. 24.3).

The preparedness phase of disaster management includes activities used to address hazards that cannot be mitigated and include planning, training and educating. One Health objectives need to work not only across species and systems but also across levels of effects (e.g. primary to tertiary and acute to long-lasting). While preparedness takes an all-hazards approach, certain hazards in specific locations present greater risks to a large swathe of the local population than do other risks. The 2019 Nebraska (USA) blizzard and the subsequent spring floods, for example, not only directly affected those individuals who needed to be evacuated, but also led to significant environmental and animal consequences (UPI, 2019). Animals trapped in floodwaters were carried downstream and ended up dispersed across a large area, impacting water quality and affecting the psychological health of locals. The flood event also overwhelmed manure management systems, and the animal waste had environmental and human health consequences as the manure may contain bacterial pathogens, concentrated nutrients and biologically active pharmaceuticals that will cause death of wildlife and aquatic species (Burkholder

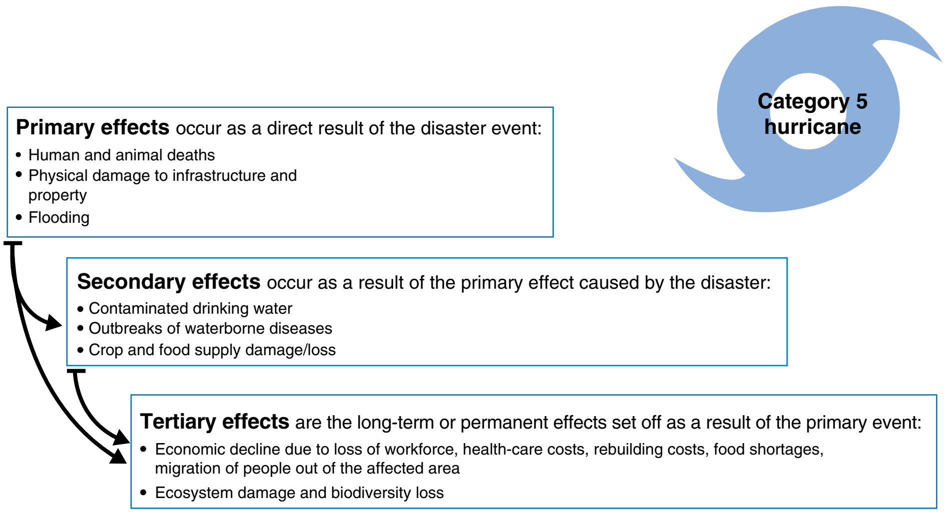

Fig. 24.3. Order of effects of disasters.

et al., 2007). The manure also led to secondary effects, such as algal blooms, that then caused additional environmental, animal and human health effects (Mallin and Corbett, 2006). The preparedness stage should involve educating the general public about their responsibilities for themselves and their animals in the event of a disaster.

Planning takes place not only at the governmental and institutional level, but also at the individual and household level. For example, individuals should keep their pet's current vaccine records, especially rabies certificates, at hand and ensure they evacuate with those records, a collar labelled with the pet's name, and the owner's name and phone number. Hurricane Katrina exposed the lack of planning for animals, specifically household pets and service animals (Swann and Lam, 2016). The dual situation of individuals refusing to be evacuated without their pets or having to abandon them to be evacuated caused the US Congress to pass the Pets Evacuation and Transportation Act of 2006 (PETS Act) as an amendment to the Robert T. Stafford Disaster Relief and Emergency Assistance Act. The PETS Act encourages state and local emergency agencies to incorporate the needs of individuals with household pets and service animals into preparedness plans. The PETS Act works in conjunction with the Post-Katrina Emergency Management Reform Act (PKEMRA), which specifically gave FEMA authority and responsibility for pet rescue and shelter. FEMA will reimburse states under the PETS Act for emergency veterinary services, services involved in dead animal removal, systems for cataloging and tracking pets, and various other costs associated with FEMA's 'Eligible Costs Related to Pet Evacuations and Sheltering' policy (DAP 9523.19) (Tinsman, 2010; AVMA, 2019a).

While the PETS Act encourages states and counties to incorporate household pets and service animals into disaster management planning to prepare rescuers and agencies to respond in an efficient and effective manner, it only takes effect after a federal declaration of disaster (AVMA, 2019a). The objectives of the response phase of disaster management focuses on the immediate needs during and immediately after a disaster, and should incorporate PETS Act objectives, regardless of whether a federal declaration is made. States or counties (or the equivalent) should have plans in place for evacuation shelters that can accommodate owners with household pets or service animals and ensure adequate veterinary and human medical care is provided on site. Individuals involved in rescue operations should have specific training on how to safely evacuate pets. FEMA has 'Animal Emergency Response' positions with minimum credentials required for each position type; however, even in federally declared disasters, non-credentialled personnel or those with little training may be charged with the responsibility of operating pet shelters (FEMA, 2007). In this case they may lack the experience specific to the nuances of animals in a disaster response situation, which could lead to more incidents of injury or disease in animals and people. Environmental contamination can quickly become a problem due to natural animal deaths and euthanasias, depending on the methodology used. Normal routes of animal disposal are not typically available early in a disaster response and carcasses can attract vermin, lead to run-off into surface water, and cause significant psychological distress for evacuees and responders. Incorporating animals into a response scenario can lead to transmission of numerous zoonotic diseases, so proper consideration must be given to proper shelter set up and epidemiology of human and animal diseases. Medical and veterinary personnel should have a means to communicate in an efficient manner to communicate information on potential zoonotic disease cases to prevent any outbreaks. Animals can act as sentinels for diseases, such as leptospirosis, *Salmonella*, *Escherichia coli* and other diseases common in a disaster or shelter environment.

The response phase is typically short lived and will transition into the recovery phases soon after the disaster ends. One Health objectives of the recovery phase should ideally restore the community to an improved pre-disaster state; however, this process can be complicated and prolonged. The recovery period not only focuses on rebuilding, but should also incorporate strategies to increase resilience to future disasters. This may include updating building codes or rezoning areas to prevent building in flood plains. The recovery period carries significant risk of stress and illness, in addition to the financial burden. Those in the agricultural sector impacted by a disaster are often affected more significantly than those who earn their livelihoods in other sectors. For example, a flood can destroy a farmer's home and also his/her livestock and therefore, his/her livelihood. This can cause financial ruin and significant psychological stress, and food insecurity for the farmer and the population supplied by the farm.

The overall objective of incorporating One Health into each of the disaster management phases is to increase the ability to mitigate risk, reduce unintended consequences, and increase overall community resilience. To accomplish this, disaster management agencies must include stakeholders from multiple perspectives within the human, animal and environmental sectors to ensure risks are anticipated and mitigated. The stakeholders should represent their individual area of expertise, but should be aware of how actions within their sector affects the other sectors. One Health is not a prescribed method, it is a multidisciplinary and interdisciplinary approach to disaster management to ensure risks within the human, animal and environmental domains are mitigated and planned for to reduce secondary and tertiary effects.

Response Roles and Responsibilities of One Health Disaster Partners

Those involved in disasters should have basic knowledge of the roles and responsibilities of the various sectors integrated within the disaster management system. While full discussion of this topic goes beyond the scope of this chapter, we provide a high-level view of involvement divided into the three One Health sectors. Commonly, emergency management authorities will have overarching leadership during disasters, with various support agencies (e.g. public health or agriculture) functioning as technical leads. Stakeholder involvement and their respective roles and organizational structure will vary between countries and situations. Stakeholders often include a combination of public and private entities who share common goals and optimally work in collaboration. Although these stakeholders have been categorically placed for clarity in this chapter, in practice there will be significant overlap between the three sectors.

Within the human domain are the physicians, nurses, community health workers, emergency medical services (EMS) personnel and other allied health and public health professionals that work in disasters. They may work on site as first responders administering prehospital care (paramedics) or in a health-care facility setting. In disaster events their primary focus is the medical care of acutely ill and injured patients. Public health personnel are concerned with the prevention of infectious disease, food protection and ensuring safe and healthy living conditions for people. Also critical to first response are law enforcement and the fire service. Law enforcement is charged with maintaining public safety, assisting evacuations, traffic regulation and search and rescue. The fire service undertakes fire protection, emergency medical response and technical rescue and extrication.

The animal domain is typically comprised of veterinarians, veterinary technicians/nurses, animal control officers, animal rescue and wildlife professionals. Persons in these designations are responsible for the health care and public health concerns of companion animals, livestock and wildlife conducted in the field or within veterinary facilities, shelters and rehabilitation centres. Individuals in agriculture and aquaculture are also represented in this sector. These farmers, herders and those involved in fishing are important as they provide essential food for impacted communities. Fortified disaster resilient agriculture/aquaculture can reduce disaster risk and support communities to economic and social recovery.

Environmental health experts conduct assessments on air, soil and water quality and the presence of hazardous substances. They aid in the humanitarian response by providing technical guidance on managing water, sewage and disaster waste systems and toxic and/or hazardous materials, which is critical to reduce human and animal suffering, protect livelihoods and boost recovery. After a disaster, environmental professionals such as engineers, urban planners and experts in sustainability, forestry, agriculture and aquatic science, along with diverse ecological specialists, can thwart negative environmental trends like soil erosion, pollution and loss of biodiversity. Ecologists are key in exploring the relationships of organisms (including humans) to each other and their biophysical environment before, during and after disasters.

There are numerous cross-cutting entities that overlap all sectors mentioned above, and therefore these have critical roles within and spanning each domain. They include government, academia, NGOs, military, industry and communities including indigenous peoples. Government bears a large responsibility for the disaster response for people, animals and ecosystems. From the local to national and international levels, governments provide a central body for coordinated action for humanitarian, animal and environmental need. Academics in education and research provide much-needed expertise and emergency voluntary support. While the biomedical and physical sciences are heavily represented in disasters, the contributions from the social sciences, economics, law and ethics should be recognized as highly valued. For example, researchers used social science to uncover insight into causes of distress and sources of resilience in Ebola survivors following the 2014 epidemic. This will inform responders about the consideration of socio-cultural complexity on community risk reduction in future disasters of infectious disease (Schwerdtle *et al.*, 2017). Efficient and effective disaster response could not be possible without the support of NGOs. NGOs are known for their rapid response and have essential roles in human and animal rescue and sheltering, provision of relief supplies and medical care. Defence forces are called to disasters when civilian authorities are overwhelmed. Given the military's technical, equipment and personnel resources, and specialized training and organization, they are often in an unrivalled position to provide humanitarian relief and environmental work. The government and aforementioned organizations cannot handle the wide scope of disasters alone, so the private sector must be heavily invested in this social responsibility. Civil society, with NGOs, provides additional surge capacity and extended capability in disasters. Business and industry represent tremendous assets, as they may supply technical services, goods and funding. Ensuring that businesses develop resilience in the form of business continuity further strengthens their support during times of disasters. Lastly, impacted communities and their surrounding communities should demonstrate proactive collective efforts in disasters. These communities are most familiar with their specific geography, vulnerable populations and livelihoods that require special attention. They know their needs very well, and how those needs should be prioritized. A bottom-up community approach working in tandem with structured governmental support will empower a community and be a catalyst for swifter response and recovery and ultimately, resilience (see Fig. 24.4).

Key messages

1. Although the response phase was highlighted above, finding opportunities to collaborate pre-event is critical to successful disaster management. In order to capitalize on relationships between response communities, opportunities must be provided to discuss human, animal and environmental health impacts as a One Health concept with all agencies and organizations, especially as these partners consider large-scale response needs for their community. Through these discussions, response needs will be addressed, but often overlooked needs such as expanded authority and the specifics of role defining will be recognized.

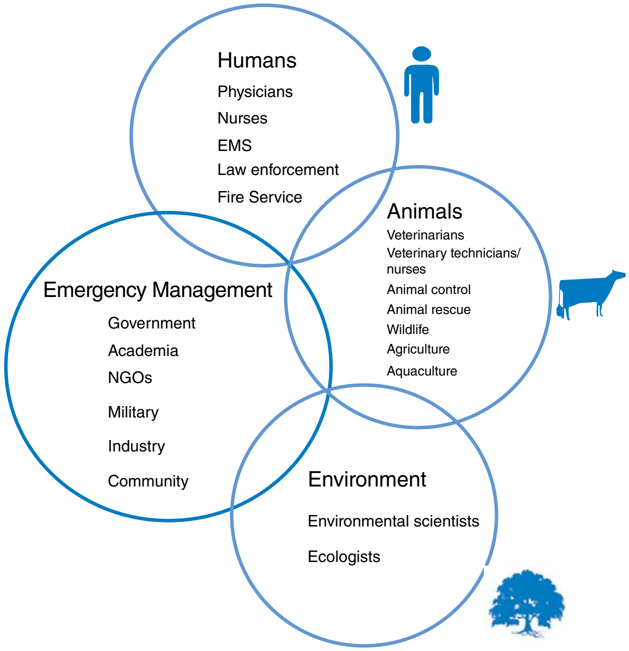

Fig. 24.4. Schematic of the disaster responders in each of the One Health domains and the cross-cutting agencies and organizations. EMS, emergency medical services; NGOs, non-governmental organizations.

2. Emergency management has a mantra: all disasters are local and all disaster response begins and ends locally. This mantra holds true in an all-hazards One Health approach as well, across the range of disasters, small to catastrophic. It is foundational that preparedness, response and recovery needs are strong at the local level.

3. To ensure that human, animal and ecosystem health needs are met synergistically during disasters, all agencies should use an organizational approach that facilitates inclusion and consideration of One Health issues. This is also the case for the representatives that coordinate involvement on behalf of their agencies. The USA's National Incident Management System (NIMS) with its Incident Command System (ICS) provide good examples of this structure (Fig. 24.5). ICS is used internationally and is a 'standardised approach to the command, control, and coordination of on-scene incident management that provides a common hierarchy within which personnel from multiple organizations can be effective' (FEMA, 2018a, p. 10). Civil organizations and NGOs should be accounted for and integrated into these systems to the maximum extent possible. FEMA's (2018b) description of the ICS is shown in Box 24.1.

Operational examples of One Health in action

Foundational One Health planning and response areas for safety and health in disasters intuitively include the following interactions between animals and humans:

- sheltering operations for animals, their owners and shelter personnel;
- first responders performing animal search and rescue, triage and medical care;
- exposure to animals at large with unknown health status including wildlife; and
- food protection.

Sheltering operations considerations

Disaster shelters can take three major forms: (i) human shelters; (ii) cohabitated shelters housing people and companion animals; and (iii) co-located shelters where people and animals are in close but different structures. Exposure to animals in shelters can lead to health concerns for humans ranging from allergic reactions, bites and other injuries, to exposure to zoonotic diseases. Team planning for

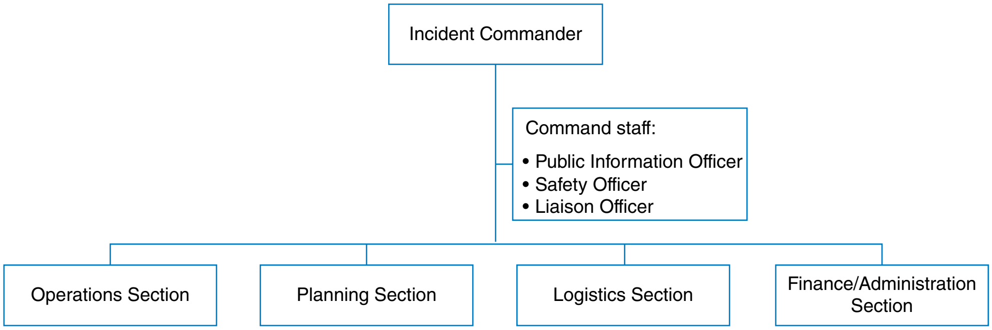

Fig. 24.5. Standard Incident Command System (ICS) organizational structure. Adapted from FEMA, 2020.

Box 24.1. The Incident Command System (ICS). From FEMA, 2018b.

A management system designed to enable effective and efficient domestic incident management by integrating a combination of facilities, equipment, personnel, procedures, and communications operating within a common organizational structure.

ICS is normally structured to facilitate activities in five major functional areas: command, operations, planning, logistics, finance and administration.

It is a fundamental form of management, enabling incident managers to identify key concerns associated with the incident, often under urgent conditions, without sacrificing attention to any component of the command system.

shelter operations should include veterinary services, public health, industrial hygiene specialists and non-governmental response groups. Together they ensure that risk assessments are performed that address the risks and exposure routes, specifically examining the types of exposures that could occur in the physical layout of the shelter and the operational flow within and around the shelter. The setting up of shelters is critical for operations and biosecurity and should include designated areas of human/animal contact, shelter rules for interaction to control how and when humans interact with animals and admission/release protocols that outline how animals are triaged, housed and released. Failure to properly establish these emergency shelters results in a breakdown of health status of the shelter precluding the movement of animals out of the shelters and reunification with their families, or placement into foster/adoptive care. Animal sheltering operations should be logistically supported and incorporated into the emergency management planning cycle so that One Health considerations continue to be factored into daily operations. Animal-focused non-governmental response organizations can be crucial partners in planning and response especially for sheltering and search/rescue for animals.

Search and rescue, triage and medical care

First responders performing the above activities should be trained and equipped with protective gear based on risk assessments performed in the area of operations. Exposure to dangerous environmental hazards (e.g. floodwaters or disaster debris), wildlife and animal diseases are among things to consider. Animal rescue may happen concurrently with human rescue, or it may occur as a separate operation. As with sheltering, search and rescue may be conducted by persons not experienced in animal behaviour or disease, so caution should be taken. If veterinary personnel are involved with search and rescue operations, animals may be triaged on site. In either situation, animals are transported to areas where they can receive necessary medical care and/or sheltering.

Exposure to unrestrained animals with unknown health status, including wildlife

This exposure poses a real and often unaddressed area of concern for One Health efforts. Animals may pose a direct exposure concern (e.g. interaction with a rabid animal) but also indirect exposure concerns such as animal waste and zoonoses (e.g. leptospirosis). Careful planning includes risk assessments crucial to identifying and preventing exposure and, mitigating exposure to animals that pose a health threat. Education and pre-event/event warnings are also important actions to help the public practise sound biosecure protective behaviours. Planning partners for this One Health area include public health, veterinary services, environmental health, public information/media and wildlife officers. It is crucial that there is ongoing communication, well prior to any emergency event, between those individuals involved in veterinary, wildlife and human responses as domestic and wildlife species may act as sentinels for human disease. Education programmes should also include schools to promote safe interactions in younger citizens.

Food protection

Food protection is an often overlooked, but critical, aspect of One Health approaches to disaster management. Disaster-damaged storage facilities within a community face food safety challenges due to power outages, exposure to rodents/insects and improper storage. As a result, food can become spoiled or contaminated with various bacterial, fungal or viral agents, causing disease. Food safety may also be compromised due to reduced regulatory oversight with food inspections. Food security often is not addressed in planning and mitigation and may go undetected during response. Food security deals with the systems that produce a society's food, and how these systems fare during and especially after disasters. Damage to farms, loss of livestock, food processing and distribution and loss of agricultural workforce could mean that an area loses key components of food production, and thus become food insecure to some degree. Extrapolated over time, typically in the recovery phase, these incremental losses could lead to the inability of that area to continue to feed itself or other trading partners to which it supplies food. This could have long-lasting regional or global impacts on food supply if a critical food product was impacted. The 2015–2016 El Niño drought in Ethiopia caused an estimated 10.2 million people to become food insecure after repeated crop failures and overwhelming loss of livestock (de Jode and Lynch, 2016). Planning and mitigation partners for food safety and security should include public health, veterinary services, agriculture and food inspection.

Challenges and Opportunities of One Health Efforts in Disasters

There are numerous opportunities for synergy across disaster agencies and programmes that currently work in the One Health space. Not surprisingly, there are also challenges as many agencies and organizations conduct business in isolation, but then are forced by events or planned activities to step outside their purview to work with their partners. While it is not possible to cover them completely, a limited discussion of such challenges and opportunities follows.

Cross-sectoral communication can have challenges in the best of circumstances, so it is not hard to imagine that communication is difficult in high-stress disaster situations. Communication is one of the largest and most commonly reported challenges in disasters. There are many layers to communication as it must exist and operate within and between individual agencies/organizations as well as provide a two-way exchange of information to and from the community. Effective communication starts with pre-event engagement and, like the response, is best organized into the ICS to ensure stakeholder involvement and information sharing.

Funding consistently plays a factor, not only in response but also in preparedness. In the case of low- to middle-income countries, a lack of funding may greatly hamper preparedness planning. When funding is available, it often follows agency/organizational priorities, budgets and authorities, and has to be repurposed to facilitate building capability and capacity across programmes and sectors. In the animal response realm, for example, funding is not generally all-hazards oriented and instead is typically allocated for animal disease events versus natural disasters. Thus, additional deliberation and creativity are required to leverage funding into all-hazards preparedness. Furthermore, many countries have made great progress in expanding the funding opportunities for companion animal response, but not nearly the same advances for livestock response. Some considerations to help address challenges utilizing existing or new opportunities include:

1. Authorities (animal health officials) for animal disease events are often non-existent at the local level for animals, but perhaps not so for public health and emergency management. Those existing agencies should work with the veterinary community to address the gaps in authority which affect funding and implementation of needed programmes. As private-sector veterinary professionals will often be acting as volunteers (which could limit participation), researching a possible reimbursement programme as part of pre-event planning for those who play veterinary preparedness/response roles in disasters could encourage involvement. This concept will continue to be a challenge in resource-poor areas. The PETS Act in the USA and the Canadian Veterinary Reserve in Canada are examples of such incentives (CVMA, 2020).

2. Expanding natural disaster preparedness and response funding to include livestock both as a source of food as well as a potential source of zoonotic diseases is needed. For example, FEMA in the USA does address livestock and poultry response if there is a potential direct human health or secondary environmental impact proven (e.g. for carcass management), but has much less provision for other aspects of response to prevent those animals from dying in disaster-related events. One substantial mitigation area in which FEMA has been involved made very credible improvements to provide buyout programmes for livestock farms in flood-prone areas. For lower income at-risk agricultural areas where buyout is not possible, examination of seasonal threats and how to mitigate impacts through temporary alterations in production levels/schedules could be very helpful on behalf of animals at risk.

3. There are some strong NGO agencies working on the animal response on the national and international level that contain some element of private veterinarian participation and personal protective equipment (PPE) training as part of their operations. The International Fund for Animal Welfare and American Society for the Prevention of Cruelty to Animals have done extraordinary work to advance response capability and capacity within their purview (IFAW, 2019; ASPCA, 2019). Perhaps additional advances in the One Health disaster space would be gained if these NGOs could be supported to partner across the human/animal response agency network to address building capability and capacity. This could help government agencies overcome the somewhat challenging siloed approach as they work with NGO partners that are more One Health oriented. Note, this should not replace direct partnering between human and animal health with emergency management. Where possible, incident management structures should include leads for both human and animal health with an emphasis that they establish and maintain a crossover function within their response objectives. Additional guidance on the One Health, multisectoral, multidisciplinary and transnational approach to zoonoses and related health threats can be found in the *Tripartite Guide to Addressing Zoonotic Diseases in Countries* produced jointly by the Food and Agriculture Organization of the United Nations, the World Organisation for Animal Health and the World Health Organization (WHO, FAO and OIE, 2019).

4. Cross-training can be a very effective partnering mechanism. Areas of cross-training that would be helpful include how public health could work with veterinarians on programmes implemented during a response to prevent outbreaks and mitigate human impact if diseases did threaten. Preparation for such events could include additional and/or advanced PPE training for veterinarians and support staff, so they are prepared to deal with zoonotic disease for natural disasters and other events. The public health/veterinary partnership could work on shelter animal care and assessment, vaccination programmes and carcass management among others. As aforementioned, funding and preparedness and response jurisdictions would need to be explored. Expanding such funding to address community protection and recovery from a One Health perspective would be a much more comprehensive and beneficial approach.

Disaster events and One Health successes and failures

Examples of translating One Health concepts into a preparedness and response strategy includes the following event stories that illustrate the value of pre-event preparedness efforts, and highlight the progress that can be made as events continue to occur over time and work is done to apply lessons learned.

Hurricanes: North Carolina (USA)

Due to insufficient planning and preparation, North Carolina encountered incredible One Health impacts due to Hurricane Floyd in 1999. The storm flooded vast areas of the state resulting in unprecedented environmental impact, as well as loss of human and animal lives and property. Lessons learned included the need to continue to assess potential impact areas for risk as those areas change over time to present new at-risk demographics as well as new response challenges. Increased animal populations presented response officials with challenges that were so overwhelming that North Carolina officials (agricultural, environmental health and public health as part of a post-review response process) recommended and implemented a mitigation buyout programme, as part of an improvement plan post-storm, of animal production farms that were located in flood zones and could not be evacuated. The resultant actions of permanently closing these farms provided not only the chance to save animal life but also protected the environment from the impact of waste management and carcass degradation in future storms. These benefits were fully realized in hurricanes Matthew and Florence, nearly 20 years later. Interestingly, though the mitigation buyout presents a seemingly overwhelmingly positive move, there should be the understanding and consideration that most decisions will have trade-offs. In this example, the unfortunate trade-off is that those farms no longer contribute to production of food, the local economy or the livelihoods of affected farm families.

Highly pathogenic avian influenza (HPAI) (USA)

HPAI in the winter/spring of 2015 proved to the US poultry industry that even extensive biosecurity measures to protect farms could be breached by viruses and cause catastrophic losses. Control methods of this zoonotic disease include depopulation of infected poultry and disposal of carcasses in a biosecure manner to prevent spread and additional loss of life. All three of the One Health components (human, animal and environment) have the potential to be impacted by the agents of zoonotic outbreaks or the response itself. This was evidenced in this event: as poultry lives were lost, responders worked diligently to prevent exposure risking human health, and struggled with the massive amounts of infected carcasses, feed and litter that needed to be properly disposed of to prevent environmental damage. Because protection of the environment was considered in policy and as a primary objective pre-event, the One Health environmental component was not overlooked. Previously, burial was the primary option for disposal of carcasses and is still used for routine mortality disposal in many situations. However, for mass mortality such as was seen in the HPAI 2015 outbreak, more environmentally conscious methods were used. Lessons learned in disposal of carcasses from previous natural disaster events, coupled with extensive disease response planning, provided a great deal of the knowledge and expertise needed to utilize these other disposal methods (composting, landfill, rendering, incineration and different types of burial). A specific example was One Health pre-event planning efforts that involved poultry industry representatives meeting with local, state and federal government health officials (public health, agriculture and environmental health) to determine the best options for disposal and the best practices for biosecurity.

Flooding: Texas (USA)

During the hurricane season of 2017, there were incredible impacts to a number of US territories and states resulting in substantial One Health response and recovery efforts. Texas dealt with extreme flooding and through heroic efforts by all involved, proved that the local response foundation built pre-event was worth every moment of time invested. One area that Texas animal health officials included in their after-action plans was defining roles and responsibilities. At the local level, animal response was a joint effort involving animal control and associated non-profit agencies (for companion animals) and cooperative agriculture extension and its response partners (for livestock/horses), together working with emergency management. At the state level, the Texas Animal Health Commission (TAHC) led a state-level response coordination centre that worked to support the local response. Noteworthy was that the TAHC, whose authority and funding is dedicated to the livestock sector, was not mandated to work with companion animals, leaving a void in who on the state level was authorized to support (in actions and funding) local response including companion animal sheltering, search and rescue, and veterinary care. Voids like this are not unique to Texas and many states find that local response involves actions that may not be supported on the regional/state level. Funding and pre-event preparedness efforts to support local response strategies are often not addressed as those issues are not a routine part of state agency programmes or priorities. This leads to a situation where local people or organizations can find themselves in a quandary as to where to request surge personnel, equipment and funding. Pre-event exercises can greatly help to identify such gaps, but only if exercise scenarios intentionally overwhelm local capacity to test the ability of state- and national-level capabilities to provide support. Texan response officials' all-hands-on-deck mentality successfully provided them with the opportunity to work through the void by developing working relationships, memoranda of understanding (MOU) and partnerships in the midst of the response. After-action workshops continue to address these void areas and have provided progress as response officials from local, state and national levels working with NGOs delineated roles and the necessary authorities to create a more robust response and support system.

Hurricanes: Puerto Rico

Somewhat unique challenges were faced by US territories through the impacts of two very large and dangerous hurricanes (Maria and Irma) in the 2017 hurricane season. Puerto Rico (PR) suffered tremendous damage and response efforts were difficult for many reasons, the most significant being the severity of the damage and that the impacted area was an island. Two One Health initiatives there proved the value of preplanning. First, the PR Department of Agriculture requested and received funding (US$12 million) from the United States Department of Agriculture to support agriculture, primarily the dairy industry, to recover (USDA, 2017). Funds were awarded to address challenges such as: (i) damage to farms; (ii) inability to access and purchase fuel for generators; and (iii) inability to use credit to purchase and replace lost/damaged feed, pay for veterinary care and lost power. Time is an incredibly critical factor when working to respond to animal husbandry challenges, especially for dairy cattle milk production. The PR Department of Agriculture provided real-time assessment of the dairy industry's needs which allowed for a timely request for assistance and funds to be quickly granted, proving the value of pre-event risk assessment and partnering on the local, state and national levels. The second example reinforces how challenging it can be to translate One Health concepts to response strategies in the midst of a catastrophic event. PR has, as many temperate locations, a substantial free-roaming and stray companion animal population. Pre-storm efforts had worked to establish sheltering, reproduction control and adoption programmes to mitigate the potential impacts that such populations could cause, ranging from human/animal health and safety concerns, to animal welfare issues and wildlife–environmental interactions. After the two hurricanes, the endemic rabies situation (exacerbated by an exposed mongoose population) as well as leptospirosis outbreaks in dogs became real human health threats and ongoing animal health problems as well (AVMA, 2019b). This loss of health status resulted in restricted movements of animals off the island to be adopted and fostered. To address the problems, animal response officials worked to craft a One Health strategy where PR veterinarians would oversee health inspections in their communities and shelters and conduct rabies and leptospirosis vaccination and education programmes. Many veterinarians were without adequate electric power and communication facilities, so efforts were made to form a partnership with public health response efforts to transport, store and distribute vaccine and enable communication to participating veterinarians. Due to the lack of pre-event planning and difficulty of communication and distribution, those efforts failed to materialize and the many veterinarians on the island could not be mobilized to bring about an effective and efficient response. By contrast, the efforts to combine the distribution of human and companion animal food, another One Health concept, was successful and allowed for synergy and more effective and efficient use of resources. These food distribution programmes benefited greatly from the response and lessons learned from previous events (i.e. Hurricane Sandy in New York/New Jersey in 2012).

Hurricanes: Caribbean

A final example of the need for a One Health approach which highlights a disappointing response effort occurred in the US Virgin Islands (USVI) after Hurricanes Maria and Irma. Because of strong winds, most livestock fencing and stored feedstuffs on the islands were damaged to such a considerable degree that large numbers of livestock, horses and poultry were roaming at large and imposing numerous threats. Animals in roadways affected traffic and interfered with response missions, thus impacting human safety. Animals, including livestock used for milk and meat, were found scavenging for food in landfills and other areas that could not only impact their health but potentially human health. Animals that remained at large could, in time, become feral and impact the environment in detrimental ways. Animal response officials proposed a request to FEMA to assist farmers to build emergency pens to restrain the animals until fencing could be repaired. Purchased feed could be used to lure animals and facilitate capture. The initiative's goals were to protect human and animal health and safety as well as mitigate damage to the environment. Due to the lack of strong partnership between federal response partners (public health and agriculture), the lack of pre-event planning and the overwhelming response/recovery issues at hand, the initiative was discussed and considered, but not granted. Efforts are still ongoing to address these issues by obtaining feed and fencing for farmers on the islands through the great work of NGOs and the USVI Department of Agriculture.

Conclusion

The relatively new One Health approach in disaster management recognizes the interconnectedness of animal, human and environmental health. It promotes collaboration between public and private entities and physicians, veterinarians, public health, social scientists and other science, health and environmentally related disciplines. This team approach must be implemented during disasters to minimize negative impacts. One Health partners have obligations, opportunities and challenges during natural and man-made disasters to support the health resiliency of people, animals and the Earth's ecosystems.

There is tremendous opportunity to work in disasters using a One Health lens. To transform the One Health concept into a strategic approach, response partners involved in human, animal and environmental health should collectively develop goals and state specific outcome objectives pre-event, that can be crafted into policy incident objectives and policy that guides response and recovery during the event. Strategies that mitigate, protect, respond to and recover aspects of these three One Health components require strong partnerships between the entities with responsibility for each respective area.

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25 Food Security and Nutrition

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Introduction

Despite advances made in food production over the past 50 years, there have also been significant shocks to the global food production system through commodity price spikes, drought, disease outbreaks and catastrophic weather events (Suweis *et al*., 2015; Laio *et al*., 2016; Lesk *et al*., 2016; Mehrabi and Ramankutty, 2019). The aim of global food security efforts is to provide all people, always, physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (World Food Summit, 1996). This is not a trivial undertaking, as the world's human population now numbers over 7.7 billion and is expected to reach somewhere between 7 billion and 9 billion by the middle of this century (United Nations, 2019). The importance of the food and nutrition security agenda is evidenced by the United Nations' Sustainable Development Goal (SDG) of Zero Hunger (SDG 2) (i.e. to end all forms of hunger and malnutrition by 2030, making sure all people – especially children – have sufficient and nutritious food in every season) (United Nations, 2015). To feed this large world population and satisfy the expected growing demand for more and safer food, and for more animal-based protein in the diets, it is anticipated that crop production must increase by over 50% and meat production by 120% by 2050 (FAO, 2009). This increased demand could, in part, be met by reducing food waste along the supply chain, since up to 50% of food produced is either lost before the commodity is harvested or wasted in processors, markets and homes (Oerke, 2006; Lundqvist *et al*., 2008). Along with the increasing demand, the escalating costs and greenhouse gas (GHG) emissions associated with food transport and storage impacts food distribution networks, increasing prices and potentially reducing access to food for those who need it most. In the past, failure to secure people's access to an affordable food supply was linked to political instability (Brinkman and Hendrix, 2011), so food security is high on the global political agenda. While the expectation is that food production will be sustainable, historically, intensive food production has been associated with soil erosion, water pollution, biodiversity loss and reduction in ecosystem services (Millennium Ecosystem Assessment, 2005), which combine to limit sustainable production.

Food security cannot be viewed in isolation. It sits within the context of the global environment and societies (Fig. 25.1). Food nutrients and food characteristics support human health and well-being and

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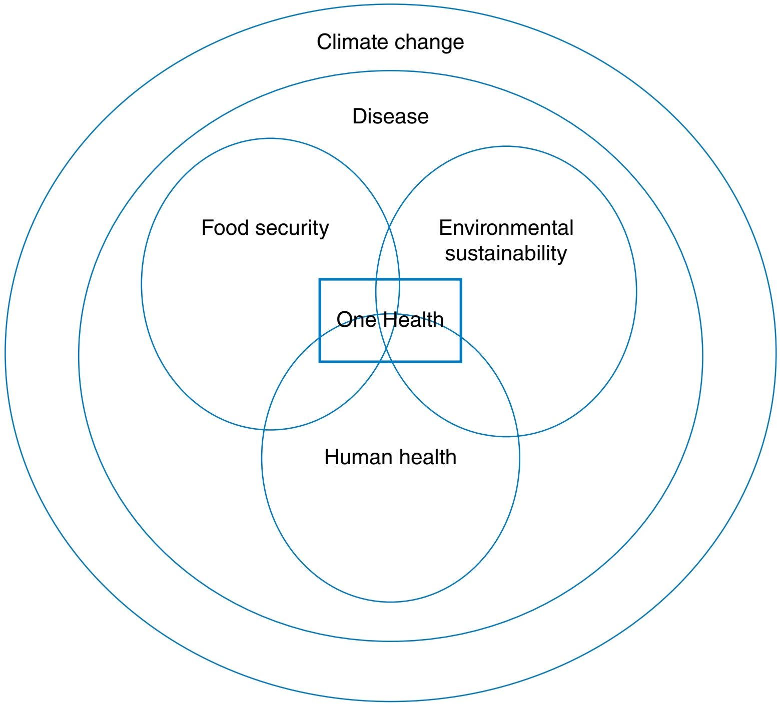

Fig. 25.1. One Health sits in the centre of a complex interacting socio-ecological system.

food systems affect environmental sustainability and of course vice-versa. Socio-economics (including governance), disease and climate change are overarching drivers, which impact the three pillars of human health, environmental sustainability and food security. These drivers are dynamic, and it is our tenet that only a systems level understanding of these components, through a One Health lens, will allow researchers, policy makers and managers to be able to put in place evidence-based solutions to the growing challenges of feeding humankind.

Our aim in this chapter is to give an overview of the relationship between food security and One Health. Additional aspects of One Health, as outlined in Fig. 25.1, are described in other chapters of the book, such as, integrated plant health (Danielsen *et al.*, Chapter 14) and climate change impacts (Stephen *et al.*, Chapter 17). In the following sections, we will outline how to provide the growing global population with the food they require and desire, considering the issues of food production and distribution patterns, especially in relation to the global governance of food and nutrition security. We highlight the fact that the relationship between food and health is central if we are to address the global challenge of food security and consider the provision of adequate nutrients to support a healthy and fulfilling lifestyle for citizens, when over 8.5% of the global population is currently obese and 11% (adults and children) are undernourished. We assess the challenge that enough food is currently produced to feed the existing population, but much of this food is wasted on the farm, in intermediary steps along the food supply chain or in consumer households. Finally, we address the relationship between food production and its associated externalities (e.g. GHG emissions, land use), and the services provided to food production from native species and ecosystems. One Health approaches, which consider human–animal–environmental interfaces, demonstrate an added value in terms of improved animal and human health, reduced suffering or sustained environmental services (Zinsstag *et al.*, Chapter 2, this volume). It is our view that these One Health approaches must be the focus if research is to address the multiple competing interests in pursuit of the SDGs.

The Global Governance of Food and Nutrition Security

Food and nutrition security are a defining challenge of the 21st century, although the exact position of the issue on the Environmental Doomsday Clock varies from year to year (Asahi Glass Foundation, 2019). The need to produce more food results from a range of drivers including the need to meet the demands from population growth, the changes in food consumption patterns associated with increasing wealth in developing countries, and societal pressure for more sustainable, biodiverse and animal-friendly agricultural systems in the developed world. Climate change also affects what crops can be grown where and how much can be produced.

While food security is the narrative that gains most of the headlines, a more relevant goal is achievement of nutrition security because extraction of nutrients and micronutrients from consumed food is a primary determinant of human health. Across the globe, 820 million people are undernourished, in terms of calorie or energy intake, and many more do not meet their macro- and micronutrient requirements (Ritchie and Roser, 2017; FAO, 2019). Of primary concern are deficiencies of vitamins (e.g. vitamin A and folate) and minerals (e.g. iron and zinc) (Bailey *et al.*, 2015), which contribute to poor growth, intellectual impairment, perinatal complications and increased morbidity and mortality. Increased focus of agricultural research on food production (particularly crops) will likely lead to an increase in the proportion of energy to micronutrients in agricultural products, further exacerbating the risks of nutrient insecurity, even in developed countries.

It has been suggested that current global food production is enough to meet the needs of every individual on the planet (Berners-Lee *et al.*, 2018). There is a large inequity of food distribution across countries, and between different ethnic and socio-economic groups within countries. Much has been written on the topic of nutritional inequity (Nisbett, 2019), however, there appears to be limited international interest in redistribution of food from areas of plenty to areas of need, other than through the free market mechanisms of exports and imports. While some experts suggest that food aid (FAO, 2001) represents a form of food redistribution, it appears that it is driven by political not humanitarian agendas (Clapp, 2015). The World Food Program (WFP) (World Food Program, 2019) is the United Nations' entity with the remit to deliver a global approach towards nutritional inequity, and WFP's focus on building within-country capacity and resilience in food and nutrition security is more sustainable in the longer term than is food aid. Although the United Nations' SDG 2 focuses on zero hunger, globally in 2016 there were over 1.9 billion overweight people (body mass index (BMI) ≥ 25) and 650 million obese people (BMI of ≥ 30), many of whom were morbidly obese (BMI ≥ 40) (WHO, 2018c). This leads to increased risk of health-related disease (primarily diabetes and cardiovascular disease) and deaths, reduced life expectancy and more years of disability during life (Lim *et al.*, 2012). While the largest rates of obesity are registered in industrialized countries, this is a growing problem in low- and middle-income countries (LMICs), which find themselves fighting a double burden of undernutrition and obesity and their interactions with other infectious and non-communicable disease (NCD).

As the potential for escalation in market prices of agricultural commodities increases, there is a changing dynamic in how countries try to ensure they have access to these commodities. One approach is to increase within-country production of commodities, as evidenced by agricultural research budgets, while also cementing relationships with other countries where the commodities are produced in excess of domestic requirements. In the 18th and 19th centuries, colonialism was, in part, related to access to food products (Nally, 2011; Duminy, 2018). Today, inter-country influence (e.g. through loans and investments) can be used to gain access to food that is grown outside country borders. As an example, some politicians have accused China of food colonialism, increasing direct access to food supplies, by, for instance, land grabs; however, this is not supported by the evidence (Bräutigam, 2018). It is plausible, however, that increasing food production in areas outside China, through government-generated loans and investments, will also increase exports from these countries to meet the growing Chinese demands for crops and meat.

The challenges within the socio-ecological system (Fig 25.1) (Zinsstag *et al.*, Chapter 2; Bunch and Waltner-Toews, Chapter 4, this volume) will increase as the human population grows, climate changes and the impacts of human activity degrade natural capital (Millennium Ecosystem Assessment, 2005). As a result, people will seek places where they can have a better life. This will relate to not only personal security but also food security (Carney, 2017). There are, and will continue to be, mass migrations of people to areas were food is perceived to be more abundant (FAO *et al.*, 2015). Migration often has a negative effect on food security as people move from a precarious agrarian lifestyle to one dependent on paid labour and food purchase (see e.g. Craven and Gartaula, 2015). The growing populism that is prevalent today (Wodak, 2015), with nationalism coming to the fore, is a major challenge for achieving food security worldwide. More and more countries will look to how they can feed their populations within the limitations of their own jurisdictions. Politicians are using food as a way of stoking nationalism (e.g. *India Today*, 2019). This jingoistic approach to food is likely to lead to global unrest and instability as in the Arab Spring (Sadiki, 2014).

The Paris Agreement brings together nations across the globe to undertake activities to combat climate change and adapt to its effects (UNFCCC, 2018). The Agreement documents the importance that climate change (Stephen *et al.*, Chapter 17, this volume), its impacts and subsequent adaptations will have on every country around the globe. The impacts will vary from region to region, with some countries impacted much more than others, independently from past and current contributions to GHG emissions. Some will benefit from increased temperatures and rainfall, while others will suffer the consequences of heatwaves, drought, floods and severe winds. These will have direct influences upon agricultural production and the food supply chain (IPCC, 2019). The indirect effects of climate change on agricultural production and food supply chains, through, for example, increased prevalence of pests and diseases, are likely to be just as detrimental to human health and well-being as the direct effects and much more likely to hit poorer countries in the developing world hardest (Juroszek and Tiedemann, 2011; Mehrabi and Ramankutty, 2019).

For the reasons cited above, One Health approaches that take a systems level approach to addressing the issues of health and environmental sustainability are well placed to address some of the governance and food systems challenges to food security. Key is to highlight the intersection of the three pillars outlined centrally in Fig. 25.1 (i.e. food security, human health and environmental sustainability), which are encompassed within the broader context of the socio-economic system, disease and climate change. The novelty of this approach is that the issues of human, animal, crop and environmental health are called to the fore, which allows food security issues associated with health to be more clearly in focus. This approach, by optimizing the health of animals, humans and the environment, will make food systems more efficient, meaning higher productivity and reduced environmental impact. Higher efficiency also means more food at lower prices in the markets, by, for example, reducing food losses due to poor animal condition or disease.

Malnutrition

Reducing malnutrition is central to SDG 2 (Zero Hunger) (United Nations, 2015). Malnutrition refers to different types of imbalances in a person's intake of energy and nutrients in relation to their requirements (WHO, 2018b). It includes two broad conditions: (i) undernutrition, or deficiency of either energy or macro-/micronutrients, leading to growth impairment (e.g. wasting, i.e. too thin for their weight; or stunting, i.e. too short for their age), and specific nutrient-deficiency diseases (e.g. anaemia), as well as increased susceptibility to infectious diseases and NCDs; and (ii) overnutrition, the other extreme, mostly referring to an excess of calories as a result of high intake of energy-dense foods (i.e. high in sugar and/or fat), combined with limited physical activity, leading to overweight, obesity and diet-related NCDs (e.g. cardiovascular disease or diabetes) (WHO, 2018c). An excess consumption of nutrients can be problematic when established tolerable upper intake levels are surpassed. These are defined as the maximum daily intake of a nutrient that is considered unlikely to pose a risk of adverse health effects to 97.5% of healthy adults (European Food Safety Authority, 2006). Adverse health effects can happen as a result of consumption of abnormally high nutrient levels in food or water. For example, excessive iodine intake was a major public health problem for the Saharawi refugees in Algeria where it was found that local animal milk was a major contributor to exceed the upper intake levels (Barikmo *et al.*, 2011). The iodine content in goat/sheep milk was positively associated with iodine content in animal drinking water, but the reasons for the high content in camel milk remained unclear (Morseth *et al.*, 2019).

Malnutrition is a complex multifactorial process. The key conceptual framework of the determinants of malnutrition was produced by UNICEF (The United Nations Children's Fund) in 1990 (UNICEF, 1990), later updated for the *Lancet* series on maternal and child undernutrition in 2013 (Black *et al.*, 2013), and adapted here in Fig. 25.2. In addition to diet, it identifies an individual's health status as a key immediate cause of maternal and child malnutrition. Similarly, undernutrition is a major risk factor for disease (Horton, 2008); therefore, a potentially lethal 'vicious cycle' exists, whereby undernutrition can lower immunity, predisposing children to repeated severe infections, with higher fatality rates, while infection can contribute significantly to deteriorating nutritional status (e.g. through loss of appetite or impaired absorption) (Katona and Katona-Apte, 2008; Walson and Berkeley, 2018). Underlying causes of undernutrition and disease are: (i) household food insecurity (e.g. absence of nutrient-dense foods); (ii) inadequate care and feeding practices (e.g. hand washing); (iii) unhealthy environment (e.g. poor water and sanitation); and, (iv) poor health services (e.g. low vaccination coverage). These are difficult to address by individual interventions; indeed, different trials aiming to break the malnutrition–environment–infection cycle, by using antimicrobial prophylaxis, or water, sanitation and hygiene interventions, have not demonstrated significant public health benefits (Walson and Berkley, 2018). Environmental enteric dysfunction (EED), a syndrome of inflammation, reducing the absorptive capacity and the barrier function of the gut, has been associated with poor health outcomes, including stunting, wasting and reduced vaccine efficacy, among children in LMICs (Crane *et al.*, 2015, Tickell *et al.*, 2019). EED has also been shown to be associated with environmental exposures, and efforts to minimize environmental contamination by improving water and sanitation can reduce diarrhoea and EDD (Tickell *et al.*, 2019). It is also believed that exposure to animal faeces, which is not explicitly addressed by conventional water and sanitation strategies, is currently an under-recognized threat to public health that requires further investigation, so that the benefits of livestock ownership are not outweighed by the risks (Prendergast *et al.*, 2019). Indeed, there are a broad suite of zoonotic pathogens from animals that

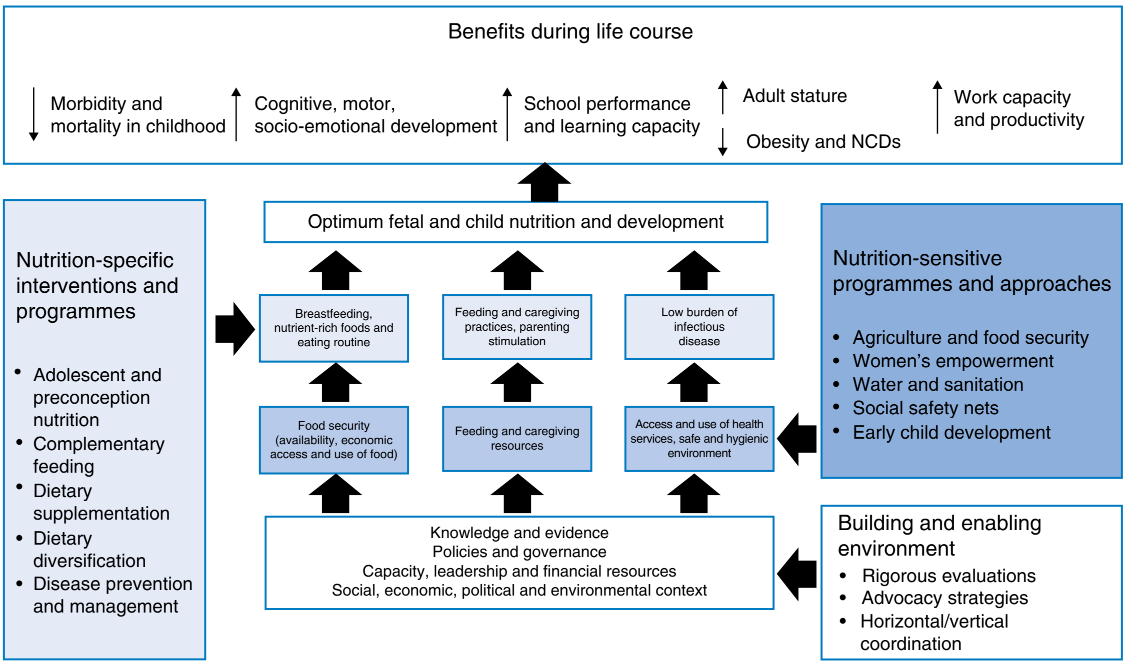

Fig. 25.2. Framework for actions to achieve optimum fetal and child nutrition and development, based on the UNICEF Nutrition Causal Framework. NCDs, non-communicable diseases. Adapted from Black *et al.*, 2013.

produce gastrointestinal diseases, such as *Escherichia coli*, *Giardia intestinalis* and *Camplylobacter jejuni*, that can be transmitted through faeces or contaminated water or food.

Undernutrition

Undernourished children are at higher risk of mortality and morbidity, and of suffering impaired growth and development (Bhutta, 2013). Wasting and stunting are two manifestations of undernutrition, requiring different prevention and treatment (Briend *et al*., 2015). Severely wasted children resulting from acute weight loss are at the most immediate risk of mortality. Globally, 7.5% of children under the age of 5 are moderately or severely wasted, amounting to over 50 million worldwide (Development Initiatives, 2018); some regions, such as South Asia, have reached the threshold of 15% (UNICEF, 2020), defined by the World Health Organization (WHO) as an emergency situation (WHO, 2000). Chronic malnutrition, on the other hand, restricts linear growth resulting in stunting. Worldwide, 150.8 million children under 5 years of age (22.2%, considered a high prevalence by the WHO (2000)) are stunted, with some countries in South Asia and sub-Saharan Africa having a very high prevalence, above 30%. Among stunted children, 3.6% are both stunted and wasted (Development Initiatives, 2018). Stunted girls are more likely to give birth to children with low birth weight, resulting in the child having delayed development, reduced earnings in adulthood, and chronic diseases (Leroy and Frongillo, 2019); therefore, stunting leads to an intergenerational cycle of malnutrition (Black *et al*., 2013). In a review from cohorts in Brazil, Guatemala, the Philippines and South Africa it was shown that undernutrition has the long-term effect of lowering human capital, with height-for-age at 2 years of age being the best predictor (Victora *et al*., 2008). These first 2 years of life, in addition to the 9 months of pregnancy, are considered a critical window of opportunity for optimal development (McDonald and Thorne-Lyman, 2017).

Children in pastoralist areas are thought to be among the most nutritionally vulnerable in the world. For example, in the Somali region in Ethiopia, children are regularly reported to have acute malnutrition prevalence above emergency levels (Sadler *et al*., 2012). In these settings, animal milk is a key resource that plays an extremely important role in nutrition. Sadler *et al.* (2009) observed that community-defined livestock interventions, targeting support for milking animals that stayed close to women and children when men left the village with the bulk of the animals to look for pasture, could improve the milk off-take. It also increased the proportion of children consuming milk and the amount consumed by each child, as well as showing general trends towards stabilized nutritional status.

Micronutrient deficiencies are widespread in developing countries; they are known as ‘hidden hunger’ because they affect the health and development of a large share of the population, without being noticed until such deficiencies become severe (Muthayya *et al*., 2013; von Grebmer *et al*., 2014). Vitamin A and zinc deficiency are key public health problems (Black *et al*., 2008) – low vitamin A, measured as serum retinol concentration below 0.70 μmol/l, affects more than half of the children under 5 (and goes beyond 80% in some countries) (Gibson, 2005; UNICEF, 2020). Vitamin A deficiency is the leading cause of preventable blindness in children and exacerbates disease due to its role in the immune system. Zinc also strengthens the immune system, as well as promoting growth, nervous system development and healthy pregnancy outcomes. Iron is critical for motor and cognitive development, and its deficiency, anaemia, is an important contributor to maternal and perinatal mortality and morbidity, and low birth weight (Gibson, 2005; UNICEF, 2020). Globally around 40% of pregnant women are anaemic, reaching 80% in some countries, and similar values exist for children under the age of 2 (World Bank, 2016).

The micronutrient content of foods can vary widely depending on several factors. Some of these are endogenous, such as plant varieties/animal breeds or animal age. Others are exogenous, such as soil, animal feed and season, production systems, etc. For example, the vitamin A content of milk depends on the vitamin A status of the livestock, which in turn depends on the beta-carotene in the forage (Calderón *et al*., 2007). On the other hand, some deficiency diseases, such as anaemia, are not only diet dependent. In LMICs, anaemia can be affected by environment-related infections such as malaria or parasitic worm infestation, such as hookworms. Hookworm eggs are deposited in faeces and once in the environment can penetrate through skin or contaminate food causing small-intestine blood loss. Similarly, *Plasmodium* causes haemolysis and is a contributor to anaemia, particularly during the rainy season when malaria transmission is highest (White, 2018).

Food safety (i.e. ensuring food free from environmental toxins, bacterial or fungal contamination, environmental heavy metals, etc.) is one of the key drivers of people's health (Havelaar *et al*., 2015). The first global assessment of the health burden associated with food safety and foodborne diseases was published by the WHO in 2015 (Havelaar *et al*., 2015). It reported that a majority of the disease burden (98%), caused by 31 prioritized food-safety hazards and estimated at 33 million DALYs (disability adjusted life years) in 2010, falls on developing countries, and particularly on children less than 5 years of age. About 35% of this burden is attributed to fresh animal-source foods, demonstrating the importance not only of processing food hygiene but also of the health of animals, produced in healthy environments. Environmental degradation such as eroded and impoverished soils has an adverse impact on the quantity and quality of the food production for animals and humans, potentially aggravating hidden hunger (Rattan, 2009). Additionally, animal diseases such as infectious bronchitis in poultry or bovine tuberculosis can impair livestock productivity and decrease the availability and quality of animal-source foods (e.g. Eisler *et al*., 2014) while also impacting wildlife in the case of bovine tuberculosis with far-reaching consequences for the affected agroecosystems (de Garine-Wichatitsky *et al*., 2013). Animal disease control activities can also have an impact in food and nutrition security (Kavle *et al*., 2015).

Overnutrition

Globally, 38.3 million children under the age of 5 years (5.6%) are overweight (Development Initiatives, 2018). Overweight is defined as excess weight-for-height/length or high BMI-for-age. In addition, 39% of the world's adult population were overweight and 13% were obese in 2016, almost tripling its worldwide prevalence since 1975 (WHO, 2018c). Although traditionally a problem for developed countries, in developing countries the nutrition transition, a shift in dietary consumption and energy expenditure that coincides with epidemiological, economic and demographic changes, has also taken place. The term nutrition transition refers specifically to changes from traditional diets, high in cereals and fibre, to more Western energy-dense diets (i.e. high in sugars, fat and animal-source foods), coupled with a decrease in physical activity, due to urbanization and more sedentary lifestyles. These changes are often the result of environmental and societal changes associated with development and the inadequacy of agriculture, health, food processing, marketing, or education policies (WHO, 2018a). These dietary trends, and the resulting food systems, have been threatening both human health and environmental sustainability. An EAT-Lancet Commission report has developed global evidence-based targets to promote healthy diets achieved through sustainable production (Willett *et al*., 2019), that need to be adapted to the socio-environmental context.

The double burden of malnutrition is characterized by the coexistence of one or more conditions of under- and overnutrition, within the same population, household or even individual, and is generally associated with poverty (Monteiro *et al*., 2004). Of 141 countries analysed in the 2018 *Global Nutrition Report*, 88% experienced more than one form of malnutrition (Development Initiatives, 2018). Altogether, malnourishment is globally responsible for more attributable deaths than any other behavioural risk factor (IHME, 2018). The key to prevention of malnutrition, in all its forms (including NCDs), is the provision of adequate nutrient-rich foods. The WHO promotes healthy diets (WHO, 2018a) that limit total and saturated fat, free sugar and salt intake, while enhancing fruit and vegetable consumption.

Given the negative externalities of agricultural production and the food supply chain (e.g. pollution, degradation of natural capital, and social injustice) the overconsumption of food/nutrients constitutes a waste within the system. Therefore, reducing overnutrition would go a long way towards improving national and global food security (Alexander *et al*., 2017).

Food Waste

Food losses represent considerable inefficiencies in the global food system and impact efforts to combat hunger, raise incomes and improve food security in impoverished areas. Even in areas with more equitable economic and infrastructure development, food losses are connected to food quality and safety inefficiencies and to environmental health. Food waste, therefore, represents a huge loss in terms of both economics and in the use of limited resources, and the externalities of producing food that is not used. Food losses are affected by crop protection, infrastructure, marketing and distribution, and consumer choice and use. Scientists, politicians and the general public are in agreement that food losses and waste need to be reduced. In the United Nations SDG 12.3 (Responsible Consumption and Production – Global food losses), countries committed to reduce food losses along production and supply chains, including postharvest losses and to halve per capita global food waste by 2030 (UN, 2015). However, while in the last decade, ongoing research has contributed new understanding on this complex topic, many questions remain, due to the lack of data, challenges with assumptions, transparency and data validity, inconsistent definitions and methodological differences (Chaboud and Daviron, 2017).

An often-cited study estimates that roughly one-third of the food produced for human consumption is lost or wasted along the entire food chain (FAO, 2011). The calculations are based on a wide range of assumed and estimated loss rates, which are then applied to Food and Agriculture Organization of the United Nations (FAO) food balance harvest quantities. Importantly, the magnitude and causes of food losses depend markedly on the specific context and conditions in a given region, country or area. Using a wet mass calculation, per capita food loss in Europe and North America was estimated at 280–300 kg/year, while in sub-Saharan Africa and South/South-east Asia the estimate was 120–170 kg/year. In developing countries more than 40% of those losses occur at the postharvest and processing levels related to storage and transport. This contrasts with industrialized countries where more than 40% of the losses occur due to wastage at the retail and consumer levels (FAO, 2011).

More recently, losses in the global food system have been categorized into agricultural production, livestock production, handling, storage and transportation, processing, consumer waste and overconsumption losses (Alexander *et al*., 2017). Agricultural production inefficiencies were the largest contributors to overall losses. The methodology considered only use and loss of harvested crops and not the contribution of grassland to animal nutrition, which understates animal impact on the agricultural system as a whole. None the less, the highest rate of losses at 81–94% (i.e. the quantity of edible animal products derived from the input of feed and harvested grass) were associated with livestock production. The proportion of global agricultural dry biomass consumed as food was estimated at only 6%, with 25% of harvested biomass consumed as food. Losses associated with overconsumption (4.5%) and consumer food waste (4.4%) were comparable. Key aspects of this study are that it analysed primarily empirical data and considered the interconnectedness of the food system and losses. The authors conclude that changes influencing consumer behaviour, such as eating fewer animal products, reducing food waste and lowering per capita food consumption would contribute meaningfully to sustainable global food security.

A review on global and European food waste analysed quantification methodologies (Corrado and Sala, 2018). An important conclusion was that robust estimates were still not possible due to the level of detail available and questions regarding the reliability and uncertainty of data. Another review on food systems and sustainability highlighted that distinct disciplinary narratives prevail, with divergent understandings about the nature of the problem, potential solutions, and how these should be prioritized (Béné *et al*., 2019). Acknowledging this multidimensionality, the authors propose entry points for a systems approach to identify the most relevant and appropriate interventions. A key finding was that little is currently known about trade-offs inherent to aligning optimal nutrition with low resource use and carbon footprints. In addition to looking for potential synergies, future research must consider how to better understand trade-offs within a One Health systems-based approach, so societies can equitably and efficiently adopt solutions.

A study using 2011 data documents a fundamental mismatch between global agriculture production and nutritional experts' balanced dietary recommendations for the world population (Kc *et al*., 2018). Kc *et al*. (2018) compared available versus healthy food scenarios, land use implications and GHG emission impacts to discuss three potential future pathways: (i) shifting to proteins which require less land and produce less GHG; (ii) using science and technology to increase crop yields; and (iii) reducing waste. Halving global household food waste, in accordance with SDG 12.3, would decrease arable land use requirements by about 10%. It should be noted that their calculations suggest that the only way to eat nutritionally balanced diets, save land and reduce GHG emissions is to produce and consume more fruits and vegetables and transition to higher plant-based protein diets.

A global perspective is imperative, but the context-specific implications on causes of, and strategies to, reduce food losses cannot be ignored. Several studies investigated aspects of consumer food waste, using directly measured data in high-income countries. In UK households, an estimated 42 daily diets were discarded per capita annually (Cooper *et al.*, 2018). A US study showed even higher losses, through including food waste from households, retailers and the hospitality industry (Spiker *et al.*, 2017). The UK study evaluated nutrition and five indicators for environmental impact as a framework to focus interventions on the foods most needed or overconsumed in the diet and where food waste has a high environmental impact. For instance, in the UK context, vegetables are wasted in large amounts, contain key nutrients for positive health outcomes and are not, on average, consumed in enough quantity. Other high-income country studies focused on specific behaviours, for example milk wastage in schools (Blondin *et al.*, 2017) and portion size choice in restaurants (Berkowitz *et al.*, 2016).

While detailed, abundant directly measured data contributes to producing high-quality investigations, for most LMICs such data is not available or severely limited in scope. Although it is known that most losses occur at the postharvest and processing level in LMICs (FAO, 2011), few studies have specifically investigated the phenomenon. One exception is the Ethiopian fishing sector, where demand exceeds supply, even though per capita fish consumption rates are among the lowest in the world (Kebede and Gubale, 2016). Postharvest losses are reported to be 40% (Tesfaye and Wolff, 2014), and attributed to harvesting immature fish, the presence of predators, high environmental temperatures, flooding and delays in marketing (Assefa *et al.*, 2018). Food safety is another aspect that contributes substantially to food losses in LMICs. In these contexts, most food is sold and bought in informal markets, which are characterized by limited and underdeveloped infrastructures. Food spoils fast in the widespread suboptimal cold chains of LMICs. Spoiled food represents a substantial contributor to food losses, putting a burden in economically vulnerable value chains. If not disposed of properly, it may also lead to disease, although this has yet to be studied. Food safety standards, enforced in most countries across the world, mean that food that does not meet food safety standards is removed from the food supply chains. In some cases, as with aflatoxin contamination of maize in Africa, this represents the condemnation of massive stocks of important food staples, threatening already vulnerable food security in many nations (Unnevehr and Grace, 2013).

Transforming our world in accordance with the 2030 Agenda for Sustainable Development requires effective partnerships across economic, social and environmental systems. Eliminating food waste is not a realistic goal, but targeted incremental steps to reduce waste in more resource-intensive areas should optimize efforts, and different strategies will need to be put in place at the same time (Foley *et al.*, 2011). To combat hunger, achieve income equity and improve global food security, more robust comparable measures are needed to quantify food waste, prioritize and set defined goals, and implement integrated action plans which encompass a collaborative One Health approach (Parry *et al.*, 2015).

Systems Approach to Food Security

Food security is highly dependent on both positive externalities impacting on it from the environment (e.g. pollination and pest control services), as well as the positive and negative externalities resulting from agricultural production, which affect the environment and can ultimately feed back with effects on agricultural production (e.g. through climate change) (Buks *et al.*, 2016; Gordon *et al.*, 2017).

Agriculture directly benefits from supporting and regulating ecosystem services (Millennium Ecosystem Assessment, 2005; Zhang *et al.*, 2007) such as soil structure and fertility, nutrient cycling, water provision, pest control and pollination (Fig. 25.3). These services are provided to agriculture at various scales, from field or farm to landscape and globally, and play an essential role in the provision of crop and livestock food products, both quantitatively and qualitatively (see also White *et al.*, Chapter 3, this volume). Native species and ecosystems also contribute to food security directly through the provision of wild foods, both animal and plant products, hunted or gathered from natural or human-transformed habitats. The importance of wild foods in the diet of people harks back to humanity's time as hunter-gathers, although it varies according to the society and environment considered, and the contributions to local and global food security are still poorly documented (Toledo and Burlingame, 2006). For instance, the capture of fish and crustaceans harvested

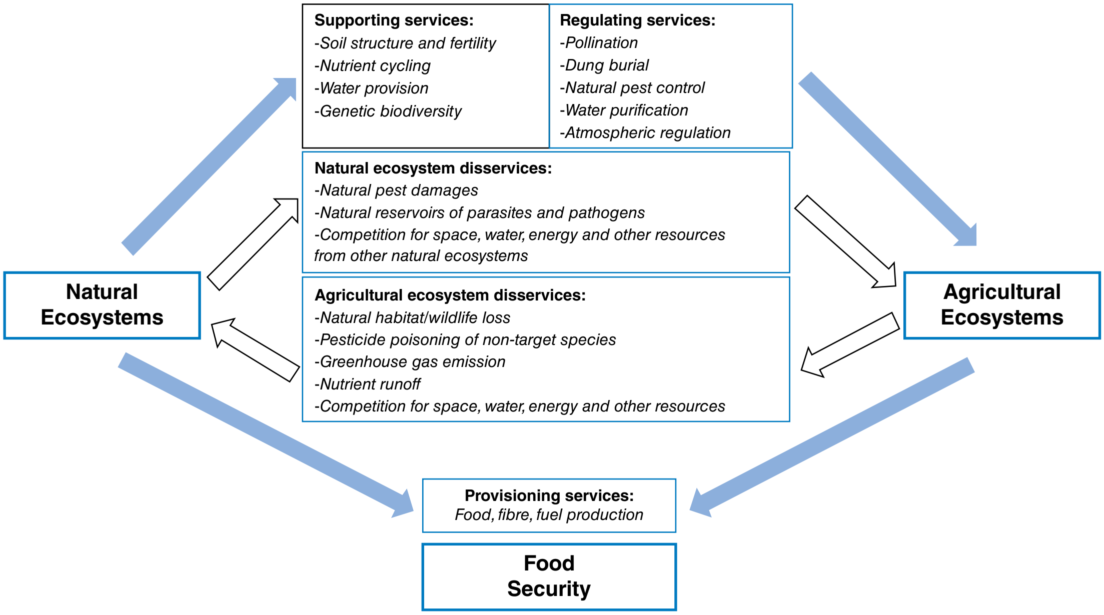

Fig. 25.3. Ecosystem services and disservices to and from agriculture and provision of food security. Blue arrows indicate positive services, whereas white arrows indicate disservices. Adapted from Zhang *et al*. (2007).

from rivers, lakes, flood plains and lagoons are a major contributor to the economy and food security of many communities in LMICs, though there is widespread recognition that this is underestimated (Godfray *et al*., 2010).

There is evidence, however, that bushmeat has long represented the main source of animal protein, and remains the key determinant of food security for millions of people across the developing world, especially in Africa, Latin America and Asia (Cawthorn and Hoffman, 2015; Perroton *et al*., 2016). But growing human populations, improved technologies and increasing commercial trade to meet the growing demand for bushmeat, often outside of the production areas, have resulted in unprecedented harvest rates and associated declines of numerous wildlife populations (Cawthorn and Hoffman, 2015; Ripple *et al*., 2016). All these threatened hunted species occur in developing countries where additional threats to wildlife include agricultural expansion and competition with livestock (Ripple *et al*., 2016). However, because wildlife has been used extensively as a coping and survival strategy securing food, cash income, health remedies, ceremonial and spiritual cleansing, and cultural and religious practices (e.g. de Garine, 1993; de Garine and de Garine-Wichatitsky, 2006), any approach focused only on biodiversity preservation and exclusion of local human populations benefiting from biodiversity as a food source runs the risk of failure in the long term (Cawthorn and Hoffman, 2015; Perrotton *et al*., 2016). In addition, bushmeat hunting and trade are associated with increased risk of disease emergence, through contacts of hunters with wild prey and their natural habitats, meat processing and indirect impacts associated with illegal logging and deforestation (Wolfe *et al*., 2005; Karesh and Noble, 2009). Highlighting the linkages between bushmeat, food security and biodiversity conservation, through a One Health approach, will provide useful indications of alternative sources of food and income, as well as the infrastructures to make these feasible.

Agricultural activities have significant environmental impacts (Buks *et al*., 2016). Agriculture is a major force behind current environmental threats, including climate change, biodiversity loss and degradation of land and fresh water (Power, 2010; Foley *et al*., 2011; IPBES, 2019; IPCC, 2019). This is especially true for conventional intensive agriculture, which has widespread environmental impacts (Garibaldi *et al*., 2017). For instance, it is estimated that 70% of the loss of terrestrial biodiversity, and up to 45% of global anthropogenic emissions of GHG, are attributable to agriculture, which adds to the considerable demand from agriculture on the freshwater resources and its contribution to desertification, salinization and soil erosion (Garibaldi *et al*., 2017). The environmental impacts of the livestock sector alone are very significant (Herrero *et al*., 2016), with an estimated 17 billion animals making use of 30% of the ice-free terrestrial mass for grazing, a third of the global cropland providing livestock feed, contributing 18% of human GHG emissions and using 32% of fresh water (Steinfeld *et al*., 2006).

Food security in Asia has historically been associated with rice production. To ensure stable prices in relation to global variation in supply, rice imports and exports have been controlled by Asian government authorities (Timmer, 2010a). Massive interventions by governments have been aimed at increasing food production, lowering food prices and providing more reliable access to food for poor households (Timmer, 2010b). These governments also worked to promote intensive rice production systems; large areas of wetlands, which had been managed for traditional agriculture for millennia, and represented a large soil organic carbon sink, have been transformed through extensive drainage into a net source of carbon dioxide (CO_2) (Nath and Lal, 2017). The integrity and broader ecosystem services of wetlands are being jeopardized by this transition to intensive land use. Failure to preserve the ecological integrity of traditional rice paddies is causing ecosystem disservices and threatening conversion of a large soil organic carbon store to GHGs (Nath and Lal, 2017).

In Thailand, for instance, rice production systems are associated with 80% of freshwater extractions in the country, and pesticide-related toxicity is becoming a major concern (Thanawong *et al*., 2014). The landscapes of the central flood plain have been extensively transformed, with far-reaching sanitary risks for humans, especially from zoonotic diseases associated with rodents (Bordes *et al*., 2017; Morand *et al*., 2019). The greatest risks of rodent zoonotic infectious diseases have been identified in the lowland rain-fed and irrigated landscapes, generally in and around rice fields (Blasdell *et al*., 2015). In addition, meat from rat species, captured in rice production areas (Fig. 25.4), which is a popular traditional wild food in Thailand and neighbouring countries, has been shown to contain significant levels of heavy metal and foodborne pathogens, including multidrug-resistant bacteria (Saengthongpinit *et al*., 2019).

Fig. 25.4. Rats captured in paddy fields and sold at road-side markets as wild food, central Thailand. Photos courtesy of M. de Garine-Wichatitsky.

Even though traditional ecological knowledge could play a significant role in addressing food security, the over-promotion of export-oriented agriculture has left lowland smallholder and subsistence rice farmers, and disadvantaged populations, in a vulnerable situation (Phungpracha *et al.*, 2016). The multiple and far-reaching consequences of the intensification of rice production in South-east Asia illustrates the convergence between food security and the One Health agendas.

Conclusion

Lessons learned are shown in Box 25.1.

The food and nutrition security agendas are two of the key challenges facing humanity in the 21st century. Providing current and future generations with a sustainable and secure supply of safe, nutritious, affordable and high-quality food is not divorced from the broad socio-ecological system. The historic isolation of the food production system from the context in which it occurs (Fig. 25.1) has led to significant human, animal, crop and environmental health issues. Environmental and socio-economic externalities significantly affect all four pillars of food security (Buks *et al.*, 2016): (i) food availability; (ii) food access; (iii) food utilization; and (iv) stability of supply and access over time. There is considerable agreement on the urgent need for a global transition to farming systems that ensure food security and nutrition, provide social and economic equity, and build and protect the ecosystem services on which agriculture and humanity depend (Garibaldi *et al.*, 2017). However, there is also considerable debate on the best approaches to achieve this.

The fundamental premise of the One Health agenda is to draw the parts of the system together (Fig. 25.1) to assess the positive, negative and perverse outcomes of decisions made in any one part of the system. In our view the integrative One Health agenda provides an appropriate framework which adds incremental value compared with those focused on individual elements of food security. The combination of human, livestock, crop and environmental health within the One Health agenda demonstrates: (i) the key need for food production to meet the nutritional needs of humans to support good health; (ii) that improvements in crop and livestock health reduce wastage in the agricultural production system; and (iii) the need to ensure healthy ecosystems to support sustained food production and human health. Measurable improvements in health of humans and animals, financial savings, social resilience and environmental sustainability all become possible when One Health approaches are applied to nutrition and food security. The linkages are particularly clearly articulated in the recent Intergovernmental Panel on Climate Change (IPCC) report *Climate Change and Land* which highlights that predicted changes in weather patterns will increase food insecurity and hunger, particularly in the most vulnerable people (IPCC, 2019).

Box 25.1. Lessons learned.

- One Health approaches to food security aim to improve health and well-being through prevention and mitigation of the negative effects of processes that originate at the interface between humans, animals and their environments, while maximizing the availability and affordability of safe and nutritious foods.
- Undernutrition is a major risk factor for disease, resulting in a potentially lethal 'vicious cycle', whereby undernutrition can lower immunity, predisposing children to repeated severe infections, with higher fatality rates, while infection can itself contribute significantly to deteriorating nutritional status.
- Animal diseases such as infectious bronchitis in poultry or bovine tuberculosis can impair livestock productivity and decrease the availability and quality of animal-source foods. They also impact wildlife as in the case of bovine tuberculosis, with far-reaching consequences for the affected agroecosystems.
- The implementation of agricultural intensification approaches has, as an example, negatively impacted the health of rice consumers and producers, including the social, economic and cultural capital of marginalized farming communities. They are also threatening the health/integrity of natural environments and of the animals that they host; including the safety of the meat of the wild rodents captured in paddy fields. One Health approaches would counter this growing trend across Asia.
- Adopting a systems-based, multisectoral, interdisciplinary perspective highlights the challenges we face regarding food security: improving food security through intensification of food production presents multiple far-reaching environmental, socio-economic, cultural and sanitary challenges.

The future is unpredictable, but certainly humanity will face challenges and stresses (e.g. climate, diseases) not seen before. The recognition that comes through a socio-ecological view of the interconnectedness of the planetary system gives hope that we will not pull levers that lead us further down a track from which we cannot escape. The future of humanity and the natural ecosystems of the world depend on us making the right decisions.

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26 Benefits of Human–Animal Interactions for Mental Health and Well-being

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Introduction

Humans all over the globe have close relationships with animals. This phenomenon has also become the subject of research in psychology and related fields. While there are a variety of relations of humans to animals, reaching from abusive and exploitative to loving, our chapter focuses on the positive and emotionally close relationships humans have with animals and on the effects that can arise from such relationships. Research provides growing evidence for a multitude of positive effects of human–animal interactions on human health and well-being and points to underlying mechanisms that explain why animals can have positive influences on human mental health. Animals represent an important part of our social environment and can provide a relevant complement to human relationships. Since one of the most important health-related factors lies in our social relationships and social support by others (Coan, 2011; Holt-Lunstad *et al*., 2015), it is not surprising that companion animals have such a significant impact on human health (Headey and Grabka, 2007). This impact of animals on human health and well-being represents an important aspect of One Health, which is reviewed in this chapter.

First, we give a short overview of the general known positive effects on human mental health and well-being from the contact with pets that are kept at home as companion animals and describe case examples of a companion animal providing social and emotional stability during a crisis and important aspects of pet keeping for healthy ageing. Subsequently, we provide an overview of specific effects on human mental health from animals introduced into interventions to address human mental health problems based on recent studies. We also give an example of a case that illustrates the importance of a One Health approach in this field by focusing on the two different sides of the partners involved: (i) the patient; and (ii) the animal.

Finally, we outline the interconnectedness of human and animal well-being in animal-assisted interventions and human–pet relationships with lessons learned as well as gaps in application of the One Health framework for animal-assisted interventions.

Effects of Pet Keeping on Mental Health

Companion animal owners often see their pets as family members (Ryan and Ziebland, 2015), reporting that their animals can effectively provide social support to them (Bonas *et al*., 2000; Doherty and Feeney, 2004; McNicholas and Collis, 2006), provide company, reduce feelings of loneliness (Stanley *et al*., 2014) and contribute to feelings of safety, especially in the case of dogs (Endenburg, 1995). Therefore, in times of stress, anxiety, grief or pain, adults and children seek proximity to their companion animals and even often prefer their presence to that of a family member or friend (Melson and

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Schwarz, 1994; Rost and Hartmann, 1994; Kurdek, 2009a,b). Parallel to the positive feelings due to the interaction and relationship with the companion animal, loss of a companion animal can lead to strong emotional reactions (Archer and Winchester, 1994). It is often perceived as the loss of a family member (Gerwolls and Labott, 1994) and linked to depressive symptoms (Stallones, 1994; Hunt *et al.*, 2008). This illustrates the quality and intensity of the relationship that humans can form with animals. Since social relationships and social support are one of the key aspects of mental health and well-being, animals play a significant role for humans. Moreover, this emotional bond from humans to their companion animals seems to be one of the factors that leads to several specific positive effects on human mental health.

For example, a relatively large body of research focused on the effect of the presence of an animal– on the one hand, on the perception of the human in its company, and on the other hand, on the stimulation of social interaction. It has widely been shown that people receive more positive attention from others in the presence of a friendly animal (e.g. individuals in wheelchairs in the company of their service dog) (Hart *et al.*, 1987). Strangers smiled more at adults in wheelchairs and started more and longer conversations with them when a service dog was present than with adults in a wheelchair without a dog (Eddy *et al.*, 2001). Similar effects were found in children with visible disabilities in a mall or at a playground (Mader *et al.*, 1989). People without disabilities also received more positive attention from strangers in public when they were accompanied by dogs (Wells, 2004). These results were found in a cultural context of Western civilization and cannot be generalized to cultures with different perceptions of animals (see also Bresalier *et al.*, Chapter 1, this volume).

Companion animals create opportunities for their owners to make new social relationships with people of different demographic and socio-economic backgrounds (McNicholas and Collis, 2000). Thus, they act as social catalysts and help to build and maintain social networks – at least in Western civilizations. Individuals with companion animals are more likely to know their neighbours, and about 40% of owners in one study reported receiving social support from people they met through their companion animals (Wood *et al.*, 2015). In a study by Gueguen and Ciccotti (2008), the company of a dog was associated with a significantly higher rate of helping behaviour from strangers on the street. This can be interpreted as an increase in spontaneous trust and social motivation. Moreover, children acquiring a new dog were visited more frequently by friends, and their families engaged in more leisure activities together 1 month after obtaining the dog than other families without a dog (Paul and Serpell, 1996).

Besides social effects studies also found psychological effects of pet ownership. For example, growing up with a pet seems to be associated with significantly higher self-confidence (Covert *et al.*, 1985). Bergesen (1989) found that the presence of an animal (different species) in a classroom increased self-confidence of children significantly over a period of 9 months, and, in particular, children with low confidence at the beginning of the study profited most. While in the family environment a direct effect of the companion animal cannot be easily derived, the results point to a potential positive effect of human–animal interaction on confidence and self-esteem. Although studies investigating effects of pet ownership on empathy face methodological problems that do not allow conclusions on cause and effect, several studies point to a potential positive effect of animal contact on human empathy (Daly and Morton, 2003, 2006, 2009). Poresky and Hendrix (1990), for example, found that the bond with a companion animal was positively related to the level of empathy and social competence in young children, assessed via reports by their mothers.

A recent review explored the role of companion animals in the development of children and adolescents. It found evidence for an association between pet ownership and higher self-esteem and reduced reported loneliness (Purewal *et al.*, 2017). A positive effect of companion animals on mental health is not only found in children. Research also documents positive effects of pet keeping for people with mental health problems (Brooks *et al.*, 2018) and that pet keeping can increase resilience in older adults against mental health disorders (Hui Gan *et al.*, 2019). Apart from these benefits, it must be kept in mind that pet ownership can also become an emotional and financial challenge, especially for older adults (Enders-Slegers and Hediger, 2019). For example, the loss due to death of a companion animal can lead to complicated grief (Brown and Symons, 2015). For older adults, the thought of rehoming a companion animal sometimes is a reason to delay a transition to assisted living, out of concern for the animal.

Pet keeping is also associated with better physical health, which in turn can be a factor that indirectly promotes better mental health. For example, pet ownership has been associated with reduced risk of cardiovascular disease or reduced poor outcomes in individuals with cardiovascular disease (Levine *et al*., 2013). Age seems to modify the association between dog ownership and myocardial infarction, with a stronger risk reduction in older age groups compared with younger age groups of dog owners (Mubanga *et al*., 2017), albeit results are sometimes contradictory (Parslow *et al*., 2005; Mueller *et al*., 2018). In several surveys with large and representative samples, dog and cat owners reported fewer visits to health-care providers and took less medication for sleeping problems than non-pet owners (Headey, 1999). Dog owners slept better, exercised more frequently, and took fewer days off from work than comparable non-dog owners (Headey *et al*., 2008). In Australia and Germany, people who continuously owned a pet over several years were the healthiest in contrast to those who had either lost or just acquired a pet. Even when controlling for age, marital status, gender, income and other variables associated with health, the dog owners reported 15% fewer annual doctor visits than non-owners (Headey and Grabka, 2007). Since most of these studies are cross-sectional, the direction of the effect is not clear (Friedmann and Gee, 2018), but it is suggested that having a companion animal can improve the owner's health and that it is not only due to the fact that healthier people adopt pets. In the case of animals requiring regular exercise, such as dogs, human health benefits may arise from increased opportunities for human physical activity. Different studies have found a relationship between dog ownership and increased physical activity in adult owners (Friedman and Krause-Parello, 2018) as well as mobility maintenance in older adults (Curl *et al*., 2017; Dall *et al*., 2017).

Case 1. Companion animals as emotional support

The fact that animals can be a stabilizing factor in times of a crisis is illustrated by the following case example from the author's practice: Suzanne, 67, had a happy marriage with Steven, 79, for over 35 years. Their two children left home many years ago to study and had their own families in other cities a few hours' drive away. Suzanne and Steven had an active lifestyle and always kept a dog. When Steven died a few months after having been diagnosed with pancreatic cancer, Suzanne was in deep grief. Even though her children came by as often as possible with the grandchildren at the weekends, it was Abby, their 3-year-old Shepherd mix, who kept her going, keeping her life together. Abby was not only there for Suzanne 24 hours a day. She provided company and slept in her bedroom, calming her disturbed sleep with her steady soft snoring. Abby was Suzanne's reason to get up in the morning, to go out for walks, to keep a regular schedule during her days, and not let herself give in to her grief and just stay in bed, doing nothing and being sad. During the long walks with Abby, she spoke with other dog owners, and received invitations for coffee when they heard that her husband had passed away. Suzanne gained two new friends, who had only been 'dog-walk-acquaintances' for some years. This social support by others and Abby helped Suzanne deal with the loss of her husband and adjust to her new situation.

Case 2. Enabling pet keeping for healthy ageing

It is a common concept in the literature that interacting with animals and pet keeping is a deep human need (Wilson, 1984) that is seen across cultures in all different parts of the world. This case example focuses on the role of pets within societal, government and organizational strategies to help older adults maintain their mental and physical health, and retain their independence. According to the World Health Organization (WHO, 2015), healthy ageing includes a person's ability to meet their basic needs, to learn, grow and make decisions, to be mobile, to build and maintain relationships, and to contribute to society. One strategy to help older adults maintain social inclusion, autonomy and quality of life and health is to enable pet ownership for those who want it (Gee *et al*., 2017; Enders-Slegers and Hediger, 2019). Social networks tend to decrease as people age by the loss of colleagues, friends and relatives and physical constraints. With that, the risk of isolation and loneliness increases (Holt-Lunstad *et al*., 2015) but companion animals may fill some gaps. Pet keeping could be a creative solution to the rising problem of a growing ageing population in the Western world. To overcome the challenges and barriers of keeping pets in older adulthood, new ideas and concepts must be addressed by the community and involvement of governments and political systems is needed. Examples are new forms of living like apartment sharing by older adults or 'generation houses' where inhabitants also share the care for a companion animal. Moreover, urban and housing planning need to take into account the increased risk of injuries and fractures in older adults due to falls associated with dogs and cats (Stevens *et al.*, 2010; Willmott *et al.*, 2012). Therefore, the environment for older adults living with pets needs to be adapted inside and outside to minimize the risks of falling among elderly pet owners when, for example, walking a dog.

A One Health perspective is important since pet keeping in older adults can also be associated with specific challenges and risks that affect the animals themselves. Strategies to ensure animal welfare must be in place since ageing often leads to a decline in physical health and strength. Providing adequate care for a companion animal might become a challenge for older adults and result in animal neglect, coexisting with the inability to take care of oneself (Lockwood, 2002). Research suggests that pet neglect is not a common problem (Pitteri *et al.*, 2014). However, this should be discussed with pet owners to find solutions, such as the mentioned generation houses that ensure that the animal's needs for a healthy life are covered.

Effects of Animal-assisted Interventions on Mental Health

Integrating animals into interventions for people with mental health problems or, more specifically, into psychotherapy, is an approach that is being increasingly used and is also receiving more attention within the scientific community. Current data generally suggest that animal assistance can enhance effects of conventional interventions (Bernstein *et al.*, 2000; Marr *et al.*, 2000; Kramer, *et al.*, 2009; Wesley *et al.*, 2009).

Recent meta-analyses and reviews suggest the biggest effect of animal-assisted therapy is on psychosocial skills, indicating it is an intervention well suited to enhance mental health and well-being. Animal-assisted therapy can lead to a reduction in depression, anxiety, loneliness, autism-spectrum symptoms, medical difficulties and behavioural problems (Nimer and Lundahl, 2007; Souter and Miller, 2007; Virues-Ortega *et al.*, 2012; O'Haire, 2013). Further research shows that animal-assisted therapy can be successfully used for clients with schizophrenia, substance abuse, dementia, depression and post-traumatic stress disorder (Kamioka *et al.*, 2014; Calvo *et al.*, 2016; Olsen *et al.*, 2016; Germain *et al.*, 2018; Jones *et al.*, 2019). Depending on the studies examined, the size of the effect of such therapy varies considerably. For post-traumatic stress disorder, for example, there is a large effect when pre- and post-animal-assisted therapy are compared, while small to medium effects are found when such therapy is compared with control interventions (Germain *et al.*, 2018). Large effects of animal-assisted interventions are found for autism-spectrum disorders, while animal-assisted interventions seem to have moderate effects on behavioural problems, depression and anxiety and small effects on cognitive ability and little effect on daily living skills (Nimer and Lundahl, 2007; Virues-Ortega *et al.*, 2012).

The presence of, or interaction with, an animal seems to improve social behaviour and social competence in different populations such as patients with acquired brain injury (Hediger *et al.*, 2019c) or children with autism (Sams *et al.*, 2006; Bass *et al.*, 2009). Positive effects on socio-emotional behaviour were also found in adults with psychiatric disorders or dementia, as well as in the elderly and prison inmates (Haughie *et al.*, 1992; Fick, 1993; Marr *et al.*, 2000; Filan and Llewellyn-Jones, 2006; Fournier *et al.*, 2007; Perkins *et al.*, 2008; Villalta-Gil *et al.*, 2009).

Interacting with an animal can lead to improved mood in chronic schizophrenia patients (Nathans-Barel *et al.*, 2005) and hospitalized children (Kaminski *et al.*, 2002). It can reduce self-reported anxiety and fear when people are exposed to a stressor (Barker *et al.*, 2003; Shiloha *et al.*, 2003; Cole *et al.*, 2007). This effect can also be observed in psychotherapy sessions (Barker and Dawson, 1998) and intervention programmes for psychiatric patients (Berget *et al.*, 2011). In addition, interaction with a dog was shown to reduce tension and confusion in elderly residents of a nursing home (Crowley-Robinson *et al.*, 1996) as well as restlessness in patients with dementia (Filan and Llewellyn-Jones, 2006; Perkins *et al.*, 2008). These reported benefits may be due to the finding that integrating animals into a therapeutic setting can have a stress-modulating effect in different populations and positively influence physical parameters (Odendaal and Meintjes, 2003; Ein and Vickers, 2018; Menna *et al.*, 2019). Interacting with a friendly animal, in particular a dog, positively affects endocrine stress responses as indicated by changes in the levels of cortisol, epinephrine and norepinephrine (Cole *et al.*, 2007), suggesting an attenuation of stress responses via human–animal interactions. It is still unclear what patients profit from most and what factors might define that a conventional therapeutic intervention leads to the same result, so that animal assistance is not needed. There is clear evidence that different patients differ in their benefit of animal-assisted interventions (Hediger *et al.*, 2019c) and future research should address this topic.

Underlying mechanisms

The promotion of social, physical and emotional well-being via animal-assisted interventions is based on a complex interconnectedness of humans and animals, including shared brain networks involving emotion, reward and affiliation (Stoeckel *et al.*, 2014). These are also the basis for meaningful social interactions and the possibility to form true social relationships, also from the animal side (Julius *et al.*, 2013). The interest of humans to relate to animals may be attributed to biophilia (a hypothesis that suggests that humans possess an innate tendency to seek connections with nature and other forms of life) (Wilson, 1984), which developed during the co-evolution of humans and animals and produced advantages for people (e.g. the utilization of animals as social support, indicators of danger, hunting mates or source of food).

The oxytocin system seems to play an important role in the positive effects of animal-assisted interventions. The interaction and relationship of people and animals can activate the oxytocin system of both humans and animals (Nagasawa *et al.*, 2015). Since the oxytocin system is activated via pleasant physical contact, touch and cuddling, the advantage of animal-assisted interventions is obvious: touch is an immanent part of animal-assisted interventions and nearly all clients want physical contact with the animal. In most human-only therapeutic approaches, however, touch is absent. Friendly physical contact, like a hug, is a most effective stress-reducing form of emotional social support (McNicholas and Collis, 2006). Oxytocin is also known as the attachment hormone, and humans do form attachment with animals (Kurdek, 2008, 2009a, b; Julius *et al.*, 2013). Due to insecure attachment or negative experiences with other humans including interpersonal trauma, it is easier for some clients to interact and build a relationship with an animal in contrast to a human, such as the therapist. Animals can serve as mediators between client and therapist (McNicholas and Collis, 2000; Wood *et al.*, 2015) and can catalyse the establishment of the trusting therapeutic relationship, which is a key factor for the success of therapy.

In such relationships, the involved animal provides the client with the chance to act as the caregiver. Displaying caregiving behaviour is a basic human need. However, it is unsuitable for human-only therapeutic relationships (i.e. the client showing caregiving towards the therapist). Caregiving towards an animal allows the client to change their role from the recipient of care (of which they often tire and become frustrated with) to the active role of the caregiver. This supports a more positive and capable perception of themselves and promotes self-efficacy, self-esteem and purpose in life. Moreover, it also activates the oxytocin system which promotes the positive effects such as improvement of mood, social motivation, communication and social interaction, and reduction of stress reactions, anxiety, pain and depression (Beetz *et al.*, 2012).

Non-verbal communication within a human–animal interaction contributes to the positive effects of animal-assisted interventions. The interaction with animals is experience oriented, and the animals give a person an immediate feedback on their behaviour. This is an advantage especially for people with language or speech problems. Animals motivate people to participate in interventions and to be more actively involved (Wohlfarth *et al.*, 2013). Another important advantage of animal-assisted interventions is that the animal does not judge people based on human standards such as looks, work success or wealth. This can reduce some social pressure, feelings of failure and shame. Altogether, these mechanisms allow an animal to be a helpful ‘bridge’ that empowers people to go to therapy and to build a trusting therapeutic relationship with another human.

Animal-assisted Therapy

Examples of animal-assisted therapy or animals visiting children in hospitals or special needs schools, older adults in nursing homes or even inmates in prisons are found throughout the globe: in North and South America, China, East and South Asia, Australia, as well as Western and Eastern Europe (Enders-Slegers *et al.*, 2019). Here, we highlight the benefits of animal-assisted therapy in two case examples: (i) for patients with disorders of consciousness; and (ii) a patient with selective mutism.

We will also comment on animal aspects of working in therapy as a relevant aspect of One Health in animal-assisted therapy.

Case 3. Animal-assisted therapy for patients with disorders of consciousness

Early rehabilitation is crucial for patients in a minimally conscious state after acquired brain injury. The goal of this treatment is enhancing the patient's consciousness by creating learning possibilities. Personally and emotionally relevant stimuli induce more reactions and better processing in patients with disorders of consciousness (Perrin, *et al*., 2015; Sun *et al*., 2018). Therefore, current treatment concepts focus on stimuli which are activity oriented and relevant for the individual patients. For many humans, animals are highly emotionally relevant (Borgi and Cirulli, 2016). This might be a reason why animal-assisted therapy is an increasingly applied approach in neurorehabilitation. Although there is growing research about animal-assisted therapy in neurorehabilitation, there are now also the first promising results for patients with disorders of consciousness. A case study documented positive effects (Bardl *et al*., 2013) and a first controlled trial investigated possible effects of animal-assisted therapy in patients in a minimally conscious state (Hediger *et al*., 2019b). In this study, ten patients each participated in eight animal-assisted therapy sessions and eight parallel conventional therapy sessions. Responses of the patients were measured via behaviour analysis, a standardized assessment and heart rate and heart rate variability measurements. Patients showed significantly more eye movements and active movements per tactile input from the therapist during animal-assisted therapy sessions compared with control sessions. In the assessment, patients also showed more overall behavioural reactions while an animal was present. The heart rate did not differ but patients showed a higher physiological arousal indicated by heart rate variability parameters (Hediger *et al*., 2019b). This indicates that animal-assisted therapy shows promise as a plausible approach to increase behavioural reactions and arousal in patients in a minimally conscious state and could be used to increase consciousness, which is a relevant therapeutic goal. Another study retrospectively analysed dog-assisted therapy sessions with 196 children and adolescents suffering from severe neurological impairments. Results showed that the most frequent reached goals targeted fun, establishing contact and communication and relaxation and that dog-assisted therapy can be a feasible approach for this population (Hediger *et al*., 2020).

This example illustrates how a One Health perspective can be beneficial when it comes to development of new treatment options – in this case for patients with severe neurological disorders. It can also help to overcome unnecessary fears of introducing animals into a hospital – given that appropriate hygiene standards and protocols regarding the animals and patients safety are in place (Hediger and Hund-Georgiadis, 2017; Hediger *et al*., 2020).

Case 4. Animal-assisted therapy for a patient with selective mutism: an author case presentation

Carla, a 4-year-old girl, was brought to psychotherapy by her mother because she did not talk to anyone outside the family (father, mother, grandmother). This problem had not been deemed too serious by the parents, until she started attending preschool 3 months earlier. The preschool teachers noted the problem and urged the parents to seek professional help.

Carla seemed very shy in the psychotherapeutic practice, avoided eye contact with the therapist and did not talk to her. However, she was very obviously interested in Kenai, the therapy dog. While the therapist and mother talked, the therapist allowed her to pet Kenai, who was lying close to the therapist. Carla listened attentively to explanations on how to pet him correctly. Asked if she had any questions about him, she gestured the therapist to leave the room, so she could speak to her mother alone. When the therapist returned, the mother said that Carla had asked to come back and visit Kenai again. A second session was arranged, and Carla was told that the next visit day was Kenai's birthday.

For the second session, Carla had drawn a picture and brought dog treats for Kenai. Even though the therapist was present, she whispered happy birthday wishes into the dog's ear. During the session, which she spent mostly petting Kenai, she whispered to her mother, while the therapist was still present. At the end of the session, which was spent talking about Kenai, Carla answered questions of the therapist non-verbally (by nodding or shaking her head) and she whispered 'bye' directly to Kenai and to the therapist when she left.

During the following three sessions, Carla dared to whisper more often to Kenai in the presence of the therapist, and began to answer more and more questions verbally, however, usually with one-word answers. She performed different tasks with Kenai, such as giving commands and playing with him with some toys (searching for them after she had hidden them). Since Kenai was also trained on non-verbal signals by the therapist, it was ensured that Kenai showed the appropriate behaviour to her commands given in a low voice with little confidence at the beginning (i.e. the therapist supported the verbal command with the non-verbal signals). At the end of the third session, Carla talked more frequently in a normal voice. The last two sessions took place with her mother remaining outside in the waiting room.

The mother reported that Carla subsequently answered questions from the preschool teacher, still with a low voice and usually with only one to two words, but communication was possible. She had greeted and answered an unfamiliar mother in the playground. The therapy went on for a total of ten sessions, with continuing improvement in communication. Different games with and without Kenai's involvement were played that needed some communication between Carla and the therapist. Carla was still shy, but she was able to communicate verbally with familiar people and occasionally also unfamiliar persons.

Case 5. The animal's view of working in therapy

Although the animal is an essential part and agent in animal-assisted therapy, there is almost no research investigating the effects on the animal's health and welfare. This topic has only recently been brought to attention since animal-assisted interventions are discussed in relation to the One Health concept (Takashima and Day, 2014; Hediger *et al.*, 2019a) and have become a focus in quality assurance and ethical debates (Ng *et al.*, 2015). Past studies investigated well-being of therapy dogs (Glenk, 2017; Corsetti *et al.*, 2019) and horses (De Santis *et al.*, 2017).

Small rodents are also often part of animal-assisted interventions but no knowledge exists of the effects on their health or well-being apart from one study that investigated effects on guinea pigs (Gut *et al.*, 2018). The investigators studied 50 observations of five guinea pigs in a randomized controlled within-subject design with repeated measurement. Each guinea pig was tested under the following conditions: (i) therapy setting with retreat possibility; (ii) therapy setting without retreat possibility; and (iii) control setting without human interaction. In the therapy setting with retreat possibility, the guinea pig was placed in a table cage together with its conspecifics and had the opportunity of choosing to interact with a patient at one side of the cage. In the therapy setting without retreat possibility, the same guinea pig was placed on the patient's lap. The behaviour of the guinea pig was coded according to a specifically designed ethogram taking human–animal interaction into account. The frequency but not the duration of hiding was significantly increased in the therapy setting with retreat possibility in comparison with the control condition. The number of comfort behaviour episodes remained constant, while the number of startling as well as explorative behaviour and the duration of locomotion increased significantly compared with the control setting. This led to the assumption that if the conditions of the therapy setting are adequate, animal-assisted therapy elicits limited stress and may possibly even provide enrichment for the involved guinea pigs. During the therapy without retreat possibility, the guinea pigs showed a higher frequency of freezing compared with the therapy setting with retreat possibility and the control setting. They did not show any comfort behaviour during therapy without retreat possibility. This provides evidence that the possibility of retreat is instrumental in reducing stress and should be provided as much as possible when animals are involved in therapeutic activities (Gut *et al.*, 2018).

In a follow-up study, we are currently combining these behavioural observations with a physiological stress indicator, using thermography to measure stress and well-being (S. Wirth, S. Gebhardt-Henrich, S. Riemer, J. Hattendorf, J. Zinsstag and K. Hediger, 2020, unpublished work). Moreover, we added a new setting and investigated 20 guinea pigs repeatedly during: (i) therapy with retreat possibility; (ii) therapy without retreat possibility; (iii) therapy with retreat possibility without presence of conspecifics; and (iv) control without human interaction. Through such research, we hope to increase knowledge about what conditions are important to ensure the health and well-being of the involved animals by combining different methods to investigate the relationship between behavioural and physical outcomes.

In the future, research should not only focus on reducing stress in animals used for animal-assisted therapy. It is also crucial to identify conditions that might provide benefits to animals participating in animal-assisted interventions and use more multidimensional, systemic approaches that include environmental factors and the social context (Hediger *et al.*, 2019a).

Conclusions

In psychology and related fields, in the past animals did not play a relevant role when it came to investigating social relationships of humans. This is now changing, and the One Health perspective helps to foster this development further. If we ignore the animals that interact with humans, we miss a highly important factor of human health. Animals cannot and should not replace human relationships. But due to their special qualities, such as unconditional acceptance (Olbrich, 2009) and non-verbal communication, animals may be more effective than human therapists, teachers or even friends and family alone in certain situations, or for some humans and under some circumstances. Furthermore, companion animals can, for example, provide close physical contact that therapists cannot provide due to social norms and the therapeutic relationship. The presence of an animal can lead to a joint focus for the therapist and patient as well as a change of roles for the patient from the only one in need to one who is able to care for another living being. The human–animal relationships should more often be the focus of many disciplines interested in human mental health.

More research and more discussions about animal welfare are needed, especially when we use animals for therapeutic means. It should be kept in mind that only healthy and mentally stable animals – from a domesticated species and well socialized with humans and their own species – should be used in therapeutic settings (Julius *et al.*, 2013; IAHAIO, 2018). Only an animal that likes to work in an educational or therapeutic setting and does so without high levels of stress will contribute in the way described above. The animal's well-being in animal-assisted interventions and companion animal ownership is of utmost importance. Consequent application of a One Health framework for animal-assisted interventions requires an interdisciplinary approach and mutual interest from both scientists and practitioners. As proposed by Hediger *et al.* (2019a), an integrated One Health study design is necessary to avoid a trade-off between human and animal health.

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27 The Spiritual Dimension of Health

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Introduction

Within the complex and all-encompassing theme of health, there is one specific aspect of human health that should not be overlooked, namely, the aspect of spiritual health. This chapter on the spiritual dimension of health begins with the crucial question: *What is meant by spirituality as part of human life?* This leads to the further inquiry: *What does it mean for an individual to be spiritually healthy?* Although answers to these questions are numerous, spiritual health and spirituality are considered in the following presentation from a dynamic perspective, in a balance between the concepts of spiritual well-being, spiritual distress and spiritual pain. To proffer an outline for the direction of this chapter: a spiritually healthy individual is a person who embodies a constructive attitude and is at peace with him- or herself, and from a monotheistic perspective, in relationship with others, God and creation. This perspective informs this chapter and is at the origin of the word 'spiritual' which is deeply rooted in a Judeo-Christian context.

The peace a person can feel encompasses the balance between self-actualization and self-giving, between being an autonomous and dependent self, as well as being in touch with the different parts of one's identity and the interaction with one's social web. From the perspective of One Health, such a holistic understanding of health is the foundation of a spiritual perspective which includes not only respect and care for people, but also the natural environment, including natural resources, animals and all of creation. It strives for a healthy balance with an ecological concern for the environment. This responsibility comes along with the ability of human beings to make ethical decisions and act on them. At the same time, it must be stated that the responsibility for all of creation surpasses the abilities of any man or woman, as it needs collaboration, coalitions and sharing synergies between families, countries and continents. Ultimately, a spiritual quality is necessary to achieve the enormous task of working for the health of people, creation and planet Earth, one that unifies people with each other and with God.

Spirituality as an Integral Dimension in Human Life and its Relation to Health

One rather general definition of spirituality is to see spirituality as opposing the materialistic sphere of existence and pointing to the world of ideas and concepts. However, one must be careful not to reduce spirituality to a static definition which would contradict a more *dynamic, holistic and integral view on human life* and human spirituality. Such an integral view on spirituality takes into account spirituality as a dynamic phenomenon in human life that exceeds any instantaneous perception of life. Spirituality itself can lead to the discovery of a person's inner dynamics and the discovery of *life as an unfolding process*.[1] The perception of

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spirituality not merely as an attitude or a state of mind helps to understand the dynamics going along with a spiritual process. Part of this process is an inner desire and the deeper awareness of belonging to an entity that transcends one's personal sensate experience, along with a growing willingness for or awareness of connectedness and a sense of wholeness (self-acceptance, living congruently with one's convictions, identity), but also of the interrelatedness of life events from birth to death. Spirituality also has to take into account the free will and choice of the human person as well as the human capacity of an inner discernment (e.g. between moral good and evil), be it prompted by self-reflection or intuition. Accordingly, spirituality is linked to a positive, constructive attitude towards life in all its dimensions.

Spirituality is related in a constructive way to the big questions of life (e.g. What is the meaning of life? Why is there suffering in the world? Why do I have to suffer? Why do I have to die? Is there life after death?) including personal convictions and doctrinal faith into one's personal world view by renouncing all too simplified answers. That is why the quest for the personal meaning of life especially in contrast to a merely biological, physical or materialistic understanding and interpretation, is often considered to be the core aspect of a spiritual search. Therefore, spirituality contributes to personal growth in identity, finding of worth and value as well as self-acceptance, linked to the phenomena of hope, faith, love, compassion and the dealing with suffering and moral evil in life, and by that spirituality also implies an ethical perspective. The acceptance in faith of a guiding principle (a higher power, God) allows answers to the big questions of life, which can contribute to greater inner strength in a crisis. External counselling (e.g. by chaplains and other representatives of religious and spiritual communities) can offer support for, rather than the solution to, this individual and highly personal dynamical process.

Spirituality as a phenomenon in human life appears in *different shapes and takes different forms*: according to the framework of rules, values and spiritual practices (like prayer or meditation) of a certain religion (e.g. Jewish, Christian, Islamic, Buddhist, Hindu, etc.), according to a specific world view or ethnic group or provenance, according to a non-specific religious stream (e.g. esoteric) or transreligious values (human rights, ecospirituality, peace movement).

Spiritual Health in the World Health Organization (WHO) Health Policy

Due to a technologically and empirically driven medicine derived from Western practice in the 20th century, spirituality and spiritual health had rarely been taken into consideration in medical treatments until the development of palliative care. The Constitution of the WHO, the International Health Conference that took place in New York on the 22 July 1946, states:

> Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity … the health of all peoples is fundamental to the attainment of peace and security and is dependent upon the fullest co-operation of individuals and States.
>
> (WHO, 2006, p. 1)

The WHO definition of health from 1946 is far-reaching in its statement, that 'health is a state of complete physical, mental and social well-being and is not merely the absence of disease or infirmity'. While health was often defined by a physical point of view frequently relying on medical concepts and analysis, the WHO definition from 1946 reflects a more holistic view to emphasize the mental and social aspects of health and well-being, which are, indeed, essential. Later on, the Ottawa Charter for Health Promotion goes even further in the exploration of what health means for the individual which is embedded into an environment and a social system by stating:

> The fundamental conditions and resources for health are peace, shelter, education, food, income, a stable ecosystem, sustainable resources, social justice and equity. Improvement in health requires a secure foundation in these basic prerequisites. … Good health is a major resource for social, economic and personal development and an important dimension of quality of life. Political, economic, social, cultural, environmental, behavioural and biological factors can all favour health or be harmful to it.
>
> (WHO, 1986, p. 1)

Health is, therefore, seen as a resource for everyday life, as a positive concept emphasizing social and personal resources, as well as physical capacities.

Deduced from this broader perspective on health that goes beyond a reductive view on biological and biochemical symptoms in body and mind, spiritual health needs a broader, more holistic perspective, taking into account the continuous process of a dynamic striving for a 'healthy balance' with respect to different factors of life, including the relation to the environment in a reciprocal perspective. Since spirituality must be considered as a dynamic process in life, any relation between spirituality and health has to take into account a dynamic understanding of health that goes beyond any reductive biological, technical or physical understanding (as would be the case for the consideration of health as 'absence of disease') (Free Medical Dictionary, 2019).

Even though it remains open what exactly is meant in the WHO 1946 definition by 'a state of complete physical, mental and social well-being' – a goal that seems unachievable in itself – health as the goal of harmony between the physical, psychological and spiritual dimensions of the human being and the environment can already be found throughout different historical, religious and cultural settings (Donev, 2000; Svalastog *et al*., 2017).

Different collectivities (such as religious groups, cultures, ethnic groups or even different subcultures within a society) offer, by their traditions or as a response to the spiritual quest of human beings, different answers and interpretations of the spiritual dimension of life and spiritual health.

This also becomes evident in the discussion on the 'spiritual dimension of health' within the WHO which should serve in the following explanations as an example and concretization.

At first sight, the very basic approach towards spiritual health is the growing interest in environmental health within the WHO from the 1950s onwards. Environmental health is concerned with the influence of the environment on human health. It gained importance under the subject of 'urban health' and 'healthy housing' (Braubach, 2014) because of a growing world population, new architectural projects (big buildings in suburban areas) and the effect of these changes on a social, mental and spiritual level (WHO, 1962). Environmental health is linked to the influence of noise, pollution and other environmental aspects on human health as a whole. On the one hand, the human being is confronted with the environment, but the human being also has wide-reaching impact on the shape of the environment that also influences its well-being, pointing to the interrelatedness of many different factors and their impact on health. So, one could say that one aspect of spiritual health is the close relation and effect of different environmental factors on human well-being and quality of life. The importance of the connection with nature is very much stretched in many aboriginal and indigenous forms of spirituality. The environment is not so much seen as an objective given reality, but as an animated, living entity and therefore the balance of life and health has to be seen in relation to the living and animated environment (e.g. in many African tribes and cultures). An example for a conception of well-being that embraces spiritual and ritual aspects within a specific culture, in this case the Maya culture, is found in Box 27.1.

This is not just an issue of indigenous spirituality, but it found its way also into the WHO discussion as underlined by the Ottawa Charter when it states in a quite far-reaching perspective:

> Our societies are complex and interrelated. Health cannot be separated from other goals. The inextricable links between people and their environment constitute the basis for a socioecological approach to health. The overall guiding principle for the world, nations, regions and communities alike is the need to encourage reciprocal maintenance – to take care of each other, our communities and our natural environment. The conservation of natural resources throughout the world should be emphasized as a global responsibility.
>
> (WHO, 1986, p. 2)

The Sundsvall Statement (1991) brought up the subject of environmental factors on human well-being, in a holistic view including the physical, socio-economic, political and also spiritual dimensions in a dynamic overall view:

> Thus action to create supportive environments has many dimensions: physical, social, spiritual, economic and political. Each of these dimensions is inextricably linked to the others in a dynamic interaction. Action must be coordinated at local, regional, national and global levels to achieve solutions that are truly sustainable.
>
> (WHO, 1991, p. 2)

Beyond that, the influence of the cultural and social aspect of spiritual health is highly esteemed, especially in non-Western regions where a traditional understanding of health is transmitted from one generation to the next and health is rather viewed from a spiritual perspective. Within the WHO South-East Asia Region, for example, increasing migration from rural to urban areas are adduced as effecting a loss of well-being and therefore a threat to health under these environmental aspects (WHO SEA, 2011). This entails the effects of a decline in the quality of social life, an increase of poverty and a deep loss of cultural and spiritual roots, including loss of knowledge about traditional healing methods.

Box 27.1. Spirit, mind, emotion and body: Maya conception of well-being. Contributed by Mónica Berger González.

The One Health Poptun project conducted in Guatemala from 2016 to 2019 aimed to develop a disease surveillance system for humans and animals in rural Maya Q'eqchi' communities of the Peten subtropical lowlands. Most families rely on traditional indigenous healers when confronted with an illness, since access to biomedical health-care services is low. We partnered with the Council of Spiritual Guides, ACGERS, to address the plurimedical reality of patients and the coexistence of spiritual belief systems associated with medical practice.

An Ajq'ij is a ritual specialist who knows the day keeping of the Cholq'ij sacred calendar and can perform ceremonies and ritual healing. An Ajilonel is an herbalist who is sought to address most ailments. In most cases a traditional healer has both of these specialties. Health in Maya epistemology is defined as Raxnaq'il Nuk'aslemal or 'well-being in our entirety of life', understood as the balance in humans resulting from the integration of four elements: (i) a healthy physical body; (ii) a healthy thought process (mind); (iii) the healthy processing of feelings; and (iv) a healthy energy-spiritual system (Berger-González *et al*., 2016). The quadripartite conception of the universe addresses four main elements (fire, earth, water, wind) associated with each quadrant of the world (east, west, south, north) and four pairs of spiritual guardians (the first grandmothers and grandfathers) that guard each quadrant/element. All medicinal plants are associated with one of these four quadrants. This basic structure guides a healer's perception of how balance between these four elements needs to be kept in humans, as well as in the continuum of relationships with all of creation. A human is not separate from the larger environment containing plants or animals, who are referred to as 'our older brothers and sisters', being they were created by 'Tzultaka' (the creator) before humans. A loss of balance in nature is understood as inevitably causing a loss of balance in humans. In this sense, Maya Q'eqchi' have an intrinsic understanding of a 'One Health' concept and afford great importance to understanding the origin of an imbalance (causing an illness), and not only of healing the disease itself. In most cases, all physical ailments are seen as the consequence of an emotional, mental or spiritual imbalance, which causes a negative energy reaction triggering the appearance of a disease in the body. This is why spiritual practice is the main source for recuperating well-being. In a sense, Maya medical practice can't exist without the spiritual-energetic dimension in people's health-seeking behaviour.

As an example, a patient diagnosed with leptospirosis within our surveillance programme, refused antibiotic treatment in the hospital unless an Ajilonel diagnosed her as well. After doing so, the Q'eqchi' specialist concluded the patient had two different diseases affecting her body plus an energetic imbalance due to suffering a 'susto', which had caused her spirit to flee her body. In his explanatory model, the patient had 'sugar in her blood' and a disease 'similar to dengue but permanent, caused by an animal'. These were made worse due to a bat that had caused the susto, 'reducing her body's ability to fight the disease on its own'. He explained the bat had come near her house due to the forest being destroyed (an imbalance in the surrounding environment). The healer recommended that the patient's spirit should be called first and two ceremonies should take place to regain her energetic strength. Afterwards he indicated the patient should take either natural herbal medicine he had, or the project's prescribed antibiotics, to treat her two diseases. The patient felt the Ajilonel, unlike the physician who gave her the laboratory results, had truly understood the origin of her imbalance, had eased her unrest by praying with her, and had saved her from 'certain death' by calling her spirit back. Once all ceremonies were completed, the patient accepted taking the antibiotics prescribed by the physician, and the healer's plants to control her diabetes.

In some regions, such as the South-East Asian Region and the Western Pacific Region, the spiritual dimension of health was seen closely linked to a quest for a more 'holistic approach', including traditional medicine and spiritual healing methods and practices (e.g. yoga, Ayurveda, traditional Chinese medicine, Maori or Australian Aboriginal health and well-being in balance with the environment) and 'human ecology' which should contribute to a wider scope of the definition of health in general (Bisht, 1985). The link between spiritual health and traditional healing methods is also emphasized in other discussions within the South-East Asia Region, revealing the influence of culture and tradition on the interpretation of health, such as the meeting of the South-East Asia Advisory Committee on Medical Research in 1983 (WHO SEA, 1984). In the Report to the Regional Director on its Ninth

Session held in New Delhi, several indications were given that the 'spiritual aspect of well-being' played an important role in the overall discussion and recommendations for further research on mental health:

> It was observed that an ecological, interactional and thus holistic perspective might be of special relevance in the field of mental health research. There might be a need for specifically strengthening ecological concepts through the development of interactional models in the field of mental health if the mental, social and spiritual components of well-being were to be equally developed.
> (WHO SEA, 1984, p. 16)

Another path of discussion about the spiritual dimension of health took place in the late 1970s and early 1980s. Under the guidance of the former WHO General Director, Dr Halfdan Mahler (from 1972 to 1988), a standing committee between the World Council of Churches and the WHO was established that over the years influenced the development of the WHO 'Health for All Programme'. The Health for All Programme was esteemed as a response to the urgent need of community-based primary health care worldwide. This programme promoted the commendable vision of giving access to primary health care to all people by the year 2000 and it was, because of its worldwide outreach and socio-economic implications, guided by a vision of a spiritual dimension. From the late 1970s onwards, lively discussions took place within the World Health Assembly about the right interpretation of the spiritual dimension of health, although no decisive answer emerged out of this highly diplomatic process (WHO 1984a,b).

Thus, starting from the World Health Assembly Health Policy diplomacy, the cultural and partially religious influence on the understanding of the spiritual dimension of health became ever more evident within the WHO regions.

Linked to the cultural concept of spiritual health, within the proclamations of the WHO Eastern Mediterranean Region, a religious understanding of the spiritual dimension of health is predominant. The Eastern Mediterranean Region embraces about 20 countries where the majority of the population is clearly Muslim, as well as countries with different religious minorities (e.g. Christians in Egypt). The widespread discussion within the Regional Office culminated in the late 1980s in a consultation called the Amman Declaration on Healthy Lifestyle ('Consultation on Islamic Lifestyles on Health Promotion through Islamic Lifestyles and their Impact on Health Development and Human Development in General') which was absorbed in 1996 in the official promulgation 'The Right Path to Health. Health Education through Religion' (WHO EMR, 1996).

A wider examination of the impact of religion on the definition of health should deepen this understanding and lead to the question of which role health plays in the three monotheistic religions of Christianity, Judaism and Islam and how spirituality and health are seen from a religious point of view as integrally or partially interrelated.

Spiritual Health and Religion

Human relatedness to nature (creation) holds an important place in most spiritualities with religious backgrounds, especially in the monotheistic religions, Judaism, Christianity and Islam where God is regarded as the origin (creator) of human beings and nature (creation). By that, monotheistic religions (Judaism, Christianity, Islam) stretch the importance of an anthropological foundation and a doctrinal embeddedness of the form and content of spirituality (e.g. certain regulations on lifestyle or the duration and frequency of prayer and meditation). The specific ethics of a religious group are closely related to its spirituality and code of behaviour (e.g. rules and convictions concerning human community, rules and convictions laid by a charismatic founding figure or founding narrative, ethics concerning the relation to nature). Spirituality in the monotheistic religions is in itself closely related to health.

Spiritual health and healing in Judaism

Judaism is the religion of the people of Israel through its history; it is founded on the covenant between Israel as the chosen People of God and God, as transmitted in the Bible and by the Mosaic Law. The Bible, the Mosaic Law and its interpretation are at the core of the Jewish lifestyle (concerning dietary regulations, the respect of the divine law) and guarantee a faithfulness to God. The Jewish spiritual tradition focuses on the Bible, its interpretation, its narratives and the tradition of the Jewish people. The Jewish tradition does not postulate a dichotomy between body and mind and has an integral perception of the human being as created by God (Blue, 1983). In ancient Israel in biblical times, any knowledge about medicine and health was esteemed as freely accessible knowledge for everyone, written down in the Tora (Mosaic Law). The treatment of current diseases was seen as being part of divine law. The Talmud, the most important tradition of interpretation, already contained in the 6th/7th century many medical observations. Even today, rabbis offer their expertise concerning the spiritual and ethical dimension of health-care issues (Navè Levinson, 1993).

Within Judaism, there also exists a spiritual school of thought and a specific method called Kaballah. Within this tradition and interpretation of Jewish spirituality, spiritual healing plays a specific role that is closely related to the Christian tradition. Especially in the 19th and 20th century, Leo Baeck and Martin Buber were prominent Jewish representatives who treated the question of healing as related to lifestyle, and were critics of any ideology, opposing ideologies which exalted self-awareness and the truisms of perceived daily life.

Martin Buber strongly affirmed the notion that disease and healing should be apprehended in a spiritual dimension in his concept of the encounter between Me and You. He summarized this view in the famous phrase: ‘All actual life is encounter’ (Buber, 2000, p. 85) (i.e. that all people, whether Tuareg shepherds or Californian film directors, become human through the encounter with other human beings). The experience and theoretical orientation of many people the world over – their basic philosophy – tells them that to encounter another human being in such a fundamental and deep way is only possible if they are also connected with the eternal Thou or the eternal Other.[2] This points to a dimension of health which the WHO definition in 1946 left out, namely, spiritual health and well-being. It corresponds to the anthropology of religions as understanding the person as a physical, emotional, mental, spiritual and social being.

One must take into account that Buber’s approach, even though universal in its outreach, is rooted in a philosophical point of view within the Judeo-Christian understanding of the person as being created in the image and likeness of God. So, one could say, generally speaking, that from a Judeo-Christian religious perspective, the emphasis of lived spirituality is connection and dialogue from spirit to spirit (i.e. to converse with God’s spirit and discover God’s intentions for one’s life, to respect and cherish others and the universe as God’s creation).

Spiritual health and healing in Christianity

The Christian tradition, separated now into different confessions and churches worldwide, considers love for God, for all human beings, fellow creatures and all creation as the core principle of a coherent Christian lifestyle. The founding figure and leading example of Christianity is Jesus of Nazareth, believed to be God who became human and is called ‘God with us (Immanuel)’ and Son of God, is seen as the foundation of the Christian community. In Jesus’ life and example, as transmitted by the New Testament, and in the early Christian communities, healing plays an important role and is esteemed as a sign of closeness to God and the breakthrough of the final arrival of the Kingdom of God that the believers are willing to accept by their own openness for a loving relationship to each other and the faithfulness to God’s revelation in Jesus. Throughout history, with the further development of Christian communities and a certain establishment of Christian faith in culture, one would now consider the following aspects as being part of spiritual health and healing in Christian communities manifesting the closeness of God’s healing presence: (i) healing prayer (free prayer or sacramental prayer); (ii) different ways of reconciliation with each other and with God, creation and other human beings; and (iii) the refutation of any moral evil (Klassen, 2011) out of respect for God’s love to each human being. Revelation (‘Christusereignis’),[3] discipleship and acceptance of God’s mercy are pillars of a Christian lifestyle. In a healthy Christian tradition, spiritual health is not merely reduced to a healing experience, but it is very much connected with the experience of spiritual consolation and isolation as significant for an individual spiritual path.

Spiritual health and healing in Islam

Islam is a religion based on the revelation received by the prophet Mohammed in the 6th century CE, transmitted in the Koran as regulations and laws for a religious lifestyle. Following the Islamic law and regulations (e.g. dietary regulations, prayer times) guarantees a life of faithfulness to God, the creator of all being. In Islam, health is esteemed as a highly valuable good and a blessing by God. Spiritual health is closely related to a life in faithfulness to the Koran and the submission under God’s almighty power and acceptance of God as the ruler over life and death (WHO EMR, 1996, p. 14). A Muslim medical doctor is seen as an authority with religious outreach, since he is responsible for resolving ethical questions when it comes to medical treatments in correlation with the regulations from the Koran and the human reason.

The Bodily Aspect of Spiritual Health

Speaking of 'spiritual health' without being determinative in the description of what 'spiritual' means, one could have the impression that body, mind and spirit are totally separate entities, which is not the case when it comes to the complex phenomenon of health. Words and thoughts give shape to our deeds and our interpretation of reality. Having said that, the dichotomic gap between the 'physical, bodily sphere' and the 'spiritual sphere' has a long tradition in the History of Ideas, holding a prominent place as early as the Hellenistic philosophic tradition (especially with Plato), with a strong counterpoint between 'soma' (Greek for body) and 'mens', 'nous' or 'pneuma' (three different terms in Greek for spirit/soul), finding its way into the philosophical and theological heritage in Eastern and Western Europe.

The anthropological triad of body, mind and spirit is etymologically at the origin of the term spirituality and serves (e.g. in Christian and Islamic anthropology) as an aid to the determination of spirituality as belonging to the 'spiritual sphere' of human existence, human perception and life.

Thanks to more recent philosophical-phenomenological concepts with the important contributions of Maurice Merleau-Ponty (2013), the intersection between body, mind and spirit is increasingly taken into consideration, so that one can speak of the importance of an embodied spirituality in order to overcome former concepts. By that is emphasized that spirituality embraces also the human body in all its functions and senses (audial, visual, haptic, olfactic and gustatic senses), as well as the external outreach to the environment (nature, fellow creatures) and the environmental surroundings itself that influences the shape of spirituality like architecture (Fries, 2017).

Spiritual Health: Between Spiritual Well-being, Spiritual Distress and Spiritual Pain

Spiritual health of human beings embraces, on an imagined continuum, spiritual well-being at one end and spiritual pain at the other, with spiritual distress emerging as a disruptive element to a spiritual equilibrium. This continuum points to the fact that spiritual health is a multi-layered phenomenon with a goal for a healthy balance, whereas spiritual well-being is mostly associated with a high quality of life. This includes, on an emotional level, harmonious aspects like connectedness, reconciliation, confidence, meaning in life, peace, love and joy. Spiritual distress, on the other hand, takes into account aspects of interdependence, vulnerability and brokenness as part of human life including feelings like fear, anger, blame, disorientation, helplessness. This leads from spiritual well-being to the other pole of the scale to spiritual pain which is experienced as a feeling of isolation, lack of sense, hopelessness, anxiety and existential fear (Best *et al*., 2015).

Very often, people who place themselves on the upper scale of spiritual well-being, would express that they feel themselves connected with others (and God), with the flow of life and that they have a deep apprehension of the meaning of life. Living according to their own convictions and values plays an important role in their lives. This bestows on them a deep feeling of coherence and identity.

Spiritual distress and pain can be caused by something that is experienced as a very personal threat to one's identity and coherent way of life. At the root of any distress is an unanswered need or desire, which points to the existential reality of human life. Therefore, speaking of spiritual needs is as important as speaking of other needs that a person feels. The more obvious need can sometimes point to a deeper need. Spiritual distress is often associated with a feeling of disintegration, a lack of identity in living out one's personal convictions and values and by the fact of not being heard in one's most inner desire, which can lead to spiritual pain. The causes for spiritual distress and pain might differ; briefly put, it can have internal or external reasons that are also partially interrelated. Internally, spiritual distress can come, for example, from unreconciled relationships with other people (and God), the fear of death as the most existential loss in human life or the non-acceptance of the given circumstances. Externally, spiritual distress and pain are very much experienced when a present situation leads to deeper, even existential, uncertainty and loss of hope and identity (e.g. by a physical disease or an accident with grave impact on health and independence or the loss of a close member of one's family, one's child or one's partner).

What can be of help in situations of spiritual distress or pain is to accept and embrace the brokenness and vulnerability of human life. Within the context of human life, it is the balance between giving and receiving, the ability to be both strong and weak, powerful and vulnerable that gives depth to life and relationships and challenges humans to act responsibly, to mature and to be able to assume autonomy and vulnerability adds a healthy humility as well as beauty to the willingness to live and learn. All of that can contribute to the goal of a spiritually healthy balance in life, leading to the feeling of more resilience and inner strength that help to overcome periods of spiritual distress and pain.

After 1950, a new approach was developed in psychotherapy that included the processes and interactions of all the members of a family when looking at an individual. Out of this approach the family system emerged as a new entity, and the systems theory evolved. In terms of psychotherapy this is described as a change of paradigm, since the systemic view looks at the emotions, thoughts and actions that happen between family members as much as those within one person (Tschanz Cooke, 2013). This dynamic systemic view leads to deeper understanding of people within their significant relationships, which is of great importance to the physical, psychosocial and spiritual health of human beings (Box 27.2). This systemic approach has been incorporated into other disciplines and professions such as pastoral counselling, social work, teaching and nursing (Latvia, 1995; Balapala, 2018; Morgenthaler, 2019; Schirmer and Michailakis, 2019).

Spirituality at the End of Life and in Palliative Care

Death, itself, is contextual: it always occurs in a certain place and at a certain time. Physicians endeavour to ascertain a cause of death; municipal agencies endeavour to settle the administrative effects of the death; legal authorities execute the will and testament of the deceased; and often religious officials preside at the ritual commemoration of the deceased person. All of this activity begs the

Box 27.2. Systemic aspects of spiritual health and well-being.

The systemic perspective enables the perception of spirituality as linked to an intentional view of One Health or ecohealth, aiming at the concern for and commitment to, the care and well-being of the self, the family, community as well as the whole world (i.e. all the linkages that make up creation). Systems theory and therapy has shown to what extent functional as well as dysfunctional family systems influence the health and well-being of people. They point out how human beings are at their core social beings in need of positive connections through relationships. Within the Judeo-Christian framework this insight is expressed in the words which describe the greatest commandment which points in the direction where complete health and well-being may be found: 'Love the Lord your God with all your heart, and with all your soul and with all your strength. This is the first and greatest commandment. And the second is like it: Love your neighbour as yourself.' This reflects an integrated view of the person as an individual (love yourself), a social being (love your neighbour) and a spiritual being (love God with heart, soul and strength). To be lovingly connected to self, to others and to God is the goal which leads to health and well-being.

An important aspect of human connectedness is the interdependence within families, friendships, and communities which can be appreciated as essential to the well-being and health of human beings. This is especially true because of its strengthening factor for the human being as a 'social being'. The social aspect includes a spiritual dimension which has a positive impact on the fundamental human constitution which includes weakness, incompleteness, dependency, brokenness and vulnerability, which, in turn, have to be accepted and integrated in a personal spiritual process. Within the Western understanding of being human there is a one-sided emphasis on strength, being in control, competence, power and knowledge. People are viewed as 'homo faber', as those in charge, those that create, know, control and act. The 'homo faber' strives to 'fabricate' his or her reality, imposing meaning on the seeming random occurrence of events. Spirituality can enable discernment of the limits of the controlling mechanism of the 'homo faber' by establishing an inner distance and self-reflection, as well as a heightened awareness of the needs of others, the environment and the need for ontological meaning. Spirituality allows the 'letting go' and the taking of an inner distance vis-à-vis the controlling and acting attitude, so that self-reflection and self-acceptance are a crucial aspect in a human being's personal and social life that contribute to advancement in self-care and care and love for others.

question of what dying means beyond a mere actuarial occurrence in a world in which, on average, over 150,000 people die every single day. The whole process of dying and the situation of a human being at the end of life, close to death, must be considered within a spiritual framework (see Box 27.3).

Because of the awareness that spiritual issues have an important place at the end of life, in 2002 the WHO added the spiritual dimension of health to the definition of palliative care. It states:

> Palliative care is an approach that improves the quality of life of patients and their families facing the problem associated with life-threatening illness, through the prevention and relief of suffering by means of early identification and impeccable assessment and treatment of pain and other problems, physical, psychosocial and spiritual.
>
> (WHO, 2002, p. 1)

This new understanding of health in palliative care was rooted in the modern hospice movement whose founding figure was Dame Cicely Saunders. Her work at St Christopher's Hospice in London has been widely influential. Her professional training in nursing, social work and medicine and her strong Christian faith, coupled with respect for all religious and spiritual values, were at the centre of the concept of total pain and total care which she developed to become the foundation of the definition of health in palliative care (Saunders, 1966).

Box 27.3. Living within a spiritual framework called creation.

Dying may be defined within a spiritual framework where life and death are seen as part of a greater entity called creation. In this understanding, the universe and all living things come into being through the will and the act of God. Even though there are differing religious and philosophical understandings of the spirit of God (i.e. the spirit of a higher power) they seem united in the understanding that there is purpose and meaning in what has been created as well as in life and death itself. Within a spiritual perspective the question of what may be described as a good life and a good death receives a special focus. This focus aims at being inclusive and holistic. It is not merely a theoretical concept, but also a transfer of faith and convictions into thought, word and deed which results in a lifestyle and an approach to death.

In her work, especially with dying patients, Cicely Saunders' focus on pain was holistic in the sense that she stressed that pain cannot be treated if pain is not seen as a phenomenon which includes psychological, social, emotional and spiritual elements. If those elements are left out, the mere physical treatment of pain is insufficient. In other words, the treatment of pain in her concept of total care needs to include the psychosocial and spiritual dimensions in order to relieve pain (Saunders, 1967).

The treatment of spiritual pain by total care therefore includes spiritual care, a service offered by theologically and psychologically trained chaplains with clinical experience in their service of ministry.

The experience of chaplains in palliative care settings (in hospitals, residential and nursing homes for senior citizens, and private homes) is therefore of relevance in view of what is important to people during their dying process. The spiritual care that chaplains offer focuses on the spiritual needs of people during the dying process. Being present at the end of life enables the discernment and determination of some characteristics which contribute to the relief of spiritual pain and to the preparation of the dying process as the final process of life where one has to let go (Bernard *et al.*, 2017).

The presence of loving and respectful people, if possible family members and friends, seems to be helpful during the dying process. Furthermore, it was observed that prayers and spiritual hymns (songs of hope and faith) lead to more calm and peace.

To arrive at the moment of death in the strength of hope requires personal, relational and spiritual resources and their activation long before death is near.

The inner, spiritual, personal and relational processes are crucial for the dying. If they receive strength from connections with people who care for them and with God, they can feel supported and gain the inner strength necessary to endure many painful hardships that can manifest at the end of life. On the other hand, what adds emotional, relational and spiritual hardship to the process of dying is, in short, not being prepared and not having peace within, between and among the most significant relationships. Therefore, the personal inner process of reconciliation with life, with broken relationships, can be healing and relieve the spiritual pain that dying people experience. Unresolved conflicts and strained relationships, spiritual uncertainty and 'unfinished business' (i.e. priorities which could not be attended to, words which still need to be said, love that wants to be expressed) all matter for the dying.

This seems to indicate that people, even at the end of life, are in need of signs of hope, love and belonging. That means, at the same time, that spirituality, independent of its religious or non-specific teleology, is also at the end of life a constructive and positive phenomenon that helps people to deepen their awareness for the mystery of life and to continue on a spiritual quest and journey.

Conclusion

Spiritual health is a phenomenon known in different religions and world views for thousands of years which is linked to the phenomenon of spirituality in human life. Depending on different convictions, faiths and beliefs, spiritual health and spirituality continue to exhibit different interpretations which are esteemed as closely linked to human health in general.

The place that spiritual health holds within a certain religious community, a culture or a society may differ. In a globalized secular world, where different religions and world views coexist, defining 'spiritual health' or the 'spiritual dimension of health' cannot be founded on one specific spirituality, religion or world view. Furthermore, speaking of spiritual health has to take into account the diversity of interpretations; one needs to enter into a profound discussion, while respecting the different traditions, historical facts and shared values. For example, from the perspective of monotheistic religions, spirituality encompasses the longing for peace with God, human beings, creation and the environment.

A first step for considering the spiritual dimension of health as important for international health policy took place within the WHO during the second half of the 20th century. Only since the end of the 20th century, largely due to the hospice movement, have spirituality and spiritual health been given more importance in palliative care, as a holistic concept of end-of-life care that also found its place within the WHO health policy.

The fact that spiritual health and spirituality are already taken into account in palliative care, and also in health-care institutions by chaplains worldwide (homes, hospitals, prisons), should be indicative of the further direction for a future worldwide health policy.

The notion of 'spiritual health' can hardly be separated from a progressive and innovative health-care policy which should not only consider clinical and technical progress, but also render proper attention to the dignity of the entire person in all its complexity, with its most inner desires and spiritual quest for healing and wholeness. Although human beings are differentiated by various religious and non-religious traditions, orientations and world views, the visceral experience of illness and ill health, and the process of dying and coping with death and bereavement transcends these differences. A spiritual health policy for 'One World' should reflect these intrinsic needs for support not only in spiritual pain and distress but also in addressing spirituality as an essential component of human health.

Thinking 'spiritual health' in regard to 'One Health' means to widen the horizon and take into account the aspect of the human environment, the human impact on the environment and the reciprocal impact that the environment has on the well-being of humans. The ethical issues concomitant with protection of the environment gain ever more importance today, becoming a holistic question of survival for the whole planet Earth as an imperative which we can only address as partners and in cognizance of the spiritual dimension.

Notes

[1] Compare this with the working definition of the Task Force for Spiritual Care of the European Association for Palliative Care. Available at: https://www.eapcnet.eu/eapc-groups/reference/spiritual-care (accessed 30 September 2019).

[2] Compare this with the different writings of Buber: (i) Buber, M. (1984) Alles wirkliche Leben ist Begegnung. In: *Werke I. Schriften zur Philosophie.* Lambert Schneider Verlag, Heidelberg, Germany, p. 85.; and (ii) Buber, M. (1984) *Das Dialogische Prinzip. Ich und Du*, 5th edn. Lambert Schneider Verlag, Heidelberg, Germany, p. 15.

[3] The 'Christ event' or 'Christusereignis' is a theological term that expresses the conviction that Jesus of Nazareth was the incarnation of God on Earth and by that, in Jesus, seen by Christians as their redeemer and saviour, the determining turning point in history took place. The event of Jesus' birth, his life and death are seen as key events for human history and therefore, the Christian religion celebrates these events.

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28 Academic and Institutional 'One Health' Research Capacity Building

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Introduction

In recent decades, the socio-economic and ecological context for human health has been changing dramatically. Health, environmental and agricultural policies are often in conflict with each other, so new and innovative approaches are urgently needed to deal with the challenges that these circumstances have engendered. Complex, messy or wicked problems (Rittel and Webber, 1973; Turnpenny *et al.*, 2009; Wesselink and Hoppe, 2010) have been emerging at an ever-increasing rate at the intersection of health, environment and society. Faced with the limits of traditional sciences and public health interventions to address these complex issues, scientists, practitioners and policy makers began to encourage integrative science through such mechanisms as the Canadian tri-council environmental health and sustainability programmes of the early 1990s (Webb *et al.*, 2010). Many initiatives have been advocated in recent years, including One Health, ecosystem health, ecosystem approaches to health, resilience thinking, social medicine, global health, ecology and health, and more recently planetary health (see also Bunch and Waltner-Toews, Chapter 4, this volume). These initiatives are, however, in the same continuum of finding solutions to difficult, cross-sectoral problems affecting human, animal, agricultural and environmental health through a transdisciplinary approach (see also Chapter 6, Berger-González *et al.*, this volume). The focus of each initiative may be slightly different but, to all intents and purposes, they are broadly similar.

These initiatives cannot be considered as being conventional research 'disciplines' and are better described as the integration and application of knowledge that derives from a broad spectrum of so-called 'domains of inquiry'. Indeed, they may be better described as 'undisciplined' approaches to address a large set of questions and problems related to the health of ecosystems. These questions, all based on uncovering and addressing 'root causes' and 'solutions', are a synthesis of conventional disciplines within the traditional sectors of natural sciences (biology, geography, infectious diseases, clinical medicine (veterinary and human), ecosystems science), health sciences (computer science, mathematics (modelling) and engineering), social sciences (anthropology, communication, political science, economics, human and animal behaviour (psychology)) and humanities.

The primary focus of this chapter is on how academia is approaching building transdisciplinary research programmes. The aim is getting people from different disciplines, with different but relevant expertise and skills, to work together to promote the

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health of all living things to build dialogue within communities and to try to find some generalizable lessons by looking at a suite of practical experiences.

Academic institutes around the world are leading the charge to enable governments and communities to more effectively respond to some of the major intersectoral health issues facing humanity. These include developing a response to antimicrobial resistance (AMR) (Szelecsenyi *et al.*, Chapter 18, this volume), mitigating and adapting to the effects of climate change (Stephen *et al.*, Chapter 17, this volume), responding to impending issues of food and water security (Gordon *et al.*, Chapter 25, this volume) and the rise of non-communicable as well as infectious diseases, and addressing human social and gender equity issues. There is also the massive issue related to degradation of our oceans, upon which we all depend for our health and well-being.

In this chapter, we aim to move a step beyond the first edition of this book, to show One Health in action in different academic institutional scenarios, focusing on the challenges, successes and lessons learned along the way. We aim to move beyond the zoonotic disease focus, bringing in more examples of environmental, social and economic determinants of health, involving government and community engagement. We will use regional/national examples from around the world to show how universities and research institutes have built and are going about building research capacity in One Health and similar approaches, both internally (within the confines of the institute) and externally (through engagement with external stakeholders, communities and partners). We will emphasize the important role that academic institutions play through their research, focusing on capacity building in the development of collaborative, transdisciplinary research programmes, and will illustrate transdisciplinary research programmes, led by academic institutes, that are being implemented and are positively benefiting 'places and people' around the world. Rather than listing and explaining these programmes in detail, the focus is on describing the challenges, successes and lessons learned, so that recommendations for 'good practice' can be identified. Case studies that illustrate the different types of research capacity being developed by academic institutions, and the different situations/issues where research capacity could be developed are highlighted.

Within academia, there is no one faculty or department at any university that houses such a diverse and essential team of collaborative researchers to address the suite of complex or 'wicked' problems that we are currently facing as a global community. Typical institutional structures are often real barriers and disincentives to building the critical 'undisciplined' mass that is needed to solve urgent and emerging problems that need the expertise and wisdom from across the entire campus (in the case of universities), and beyond. Most universities around the world separate research by discipline into faculties and departments, however, the primary goal of these units is often to preserve and protect their discipline. For example, an innovative approach to knowledge integration, such as hiring an epidemiologist into an infectious disease programme, can be met with strident opposition from researchers ('epidemiologists belong in the Department of Epidemiology'). In other cases, attempts at promoting cross-disciplinary collaborations disadvantage individuals, such as when a community-based social scientist researcher receives an academic appointment in the Department of Pathology and spends 6 years that are difficult and challenging attempting to meet that department's requirements for promotion and tenure.

For academic institutions to rise to this challenge, they need to therefore change or adapt their institutional structure and culture. Creating a transdisciplinary programme within an academic institution designed around disciplines is challenging, especially when there is a high degree of academic competition associated with ambiguous authorship, and what is most highly valued is single-authorship 'stardom'. Other significant challenges include personality conflicts, poor social and communication skills on all sides (academic and technical skills being more highly valued) and the fear that veterinarians and physicians are trying to 'medicalize' ecology. Finally, and critically, there is limited or erratic research funding available for transdisciplinary research programmes, as well as publication biases, with the majority of funding bodies not recognizing that health, environmental and social problems cannot be solved in isolation from each other.

Different types of research programmes require different types of capacity, depending on where their goals fall in the research spectrum from basic to applied, as they relate to the application of the One Health approach. This chapter explores how some academic institutions around the world have developed their transdisciplinary research programmes from both internal and external perspectives. From an internal perspective, it will show, through case study examples, how academic institutions are adopting a transdisciplinary research culture. From an external perspective, it will show how One Health academic and research institutes, centres, networks and communities of practice have approached developing and conducting research programmes that are focused on building One Health capacity in government departments and local communities. Box 28.1 provides a list of important definitions and Box 28.2 outlines the focus of the chapter.

Box 28.1. Important definitions.

- One Health is a transdisciplinary approach that integrates the natural, health and social sciences and the humanities in striving for ecosystem health.
- Health is a social construct that has a diversity of definitions ranging from the absence of diseases, to homeostasis and normal function, to capacity to meet the expectations and challenges of everyday living. We recognize this diversity in this chapter, while advocating for the conception of health as capacity to adapt, respond to, or control life's challenges.
- An ecosystem is all the plants, animals and humans that live in a particular area together with the complex relationship that exists between them and their environment.

Box 28.2. Focus of the chapter.

Academic and institutional One Health research capacity building to develop:

- *People* – researchers, leaders, advocates, champions, practitioners:
  - with experience fielding, identifying and dealing with researchable problems/goals that require a transdisciplinary approach;
  - with the necessary education, skills, experience and attitudes to work in a transdisciplinary setting; and
  - having a diverse repertoire of communication strategies, listening skills and metacognition abilities;
- *Knowledge* – in priority problem areas at the interface between human, animal, plant and environmental health (e.g. zoonotic diseases, food and water security and safety, wildlife diseases, ecotoxicology, epidemiology, AMR, climate change).
- *Networks and collaborations* – promoting functional two-way channels of communication between the scientific community and the communities with whom they work. Regular scientific meetings to enable like-minded people to share experiences to grow the One Health and other similar approaches.

Case Studies

Case studies illustrate the different ways that universities/research institutes around the world are currently building capacity in One Health/transdisciplinary (and related approaches) research. The following examples will be described:

- the 'One Health institute' model (Case study 1);
- the 'transdisciplinary centre' model (Case studies 2, 3 and 4); and
- building communities of practice and networks (Case study 5).

Case study 1. Perspectives from the programme and philosophy of the University of California Davis One Health Institute (UC Davis OHI) including how One Health transdisciplinary research capacity was built nationally, regionally and internationally.

Promoting transdisciplinary collaborations can be framed using a specific problem or using an umbrella-process approach. Within a university setting, One Health units often focus on the process of fostering dialogue and action to address a variety of One Health issues. The UC Davis OHI is one example. The OHI provides premier education and training, conducts innovative and cutting-edge research, and facilitates capacity building across partners and stakeholders at local, regional, national and international levels to advance knowledge and solve a multitude of complex problems at the nexus of human, animal and environmental systems. At UC Davis, the OHI began as the Wildlife Health Center in 1997, and then expanded in 2009 as an umbrella unit to include centres and programmes that had strong public health and environment components, facilitating a culture of team-oriented One Health problem-solving and integrated expertise involving input from the natural, health and social sciences sectors.

The UC Davis OHI fosters collaboration by co-locating faculty, staff and students at UC Davis and international sites. Co-location may take the form of daily interactions at the university: for instance, the OHI is located at the School of Veterinary Medicine, or it may use an intensive workshop or short-course format at sites around the world. The goal is to provide experts and stakeholders opportunities to get to know each other, professionally and personally, so that they find ways to work together that advance knowledge and breakthroughs that improve the health of people, animals and the planet.

OHI programmes and projects

Transdisciplinary collaborations are central to the success of the UC Davis OHI. By working across traditionally siloed academic disciplines, One Health education and research activities leverage strengths from across specialties, demonstrating the ways in which coordinated efforts can solve multidimensional challenges. The UC Davis OHI is home to numerous centres (e.g. Karen C. Drayer Wildlife Health Center, California Raptor Center, Planetary Health Center of Expertise (PHCOE), EpiCenter for Disease Dynamics), programmes (e.g. One Health Laboratory, Students for One Health), and projects (e.g. Health for Animals and Livelihood Improvement (HALI), PREDICT, PREEMPT, Global Virome Project). Overall, the OHI strives to enhance health around the world by strengthening a workforce capable of rapidly responding to and mitigating disease threats across the human, animal and environmental health sectors. This involves classroom as well as hands-on training activities.

Global environmental change, which includes climate change, changes in ecosystems resulting from loss of biodiversity, shifts in land use, and population growth, is an imminent threat to global human, animal and environmental health. Limited resources, including funding, personnel and time, necessitate that global health research is both efficient and productive. A few projects exemplify the OHI's approach by fostering collaboration to directly and indirectly address current and future global environmental change. A flagship OHI programme that addresses these topics is the Rx One Health Summer Institute, which was established in 2016 and has been running in Tanzania as a 1-month field course for graduate students and early career professionals. The Rx One Health program is transformational because it gives 22 participants at a time, half from developed and half from developing countries, access to immersion experiences to build their competencies in One Health as they move around the country to work on issues such as pollution, food security, water quality, and zoonotic disease prevention and control. The course is co-led by UC Davis and Sokoine University of Agriculture in Tanzania, representing a strong North–South One Health partnership that has been operating since 2006 as the HALI Project (Mazet *et al.*, 2009).

Since 2009, the OHI has led the USAID-funded PREDICT programme that provides surveillance and discovery of emerging viruses in viral families such as filoviruses (e.g. Ebola), influenza, coronaviruses, paramyxoviruses and flaviviruses, since these viruses can have wildlife reservoirs and move among people, wildlife and livestock with pandemic potential. PREDICT operates in more than 30 countries worldwide and works with local universities as well as ministry partners to evaluate behaviours, practices, ecological and biological factors that drive disease emergence, transmission and spread at key wildlife–human interfaces (see the infectious diseases discussed in Chapters 18–22, this volume).

Continued

Case study 1. Continued.

The EpiCenter for Disease Dynamics uses epidemiological and mathematical analytical tools and methods to better understand the ways in which animal, human and environmental mechanisms contribute to disease emergence and distribution. Researchers have used transmission, environmental and physiological features of wildlife hosts to identify potential geographic regions where harmful flaviviruses like dengue, Zika, West Nile and yellow fever could observe sustained transmission (Pandit *et al*., 2018). Such models are critical in developing surveillance and detection systems that could prevent changes in global disease transmission (Chitnis *et al*., Chapter 12, this volume).

The PHCOE works across all ten of the University of California campuses as part of the larger University of California Global Health Institute (UCGHI). Originally a One Health Center of Excellence (COE), PHCOE evolved into part of the University of California's system-wide effort. The PHCOE launched in 2016 and focuses on complex issues arising from global climate change, population growth and limitations to food and natural resources. PHCOE uses community engagement as well as local and international partnerships to identify ways in which humans and animal populations can foster resilience in the face of environmental change. A key component of PHCOE is education. Numerous fellowships, international field courses and ambassador programmes expose students to planetary health issues that require critical thinking skills, cooperation and collaboration to work towards a more sustainable future for our populations and our planet.

Lessons learned

Both top-down and bottom-up approaches can be used to foster One Health problem solving. At UC Davis, the OHI model grew and became successful using a bottom-up approach driven by faculty, students and stakeholders. The model was taken up at other universities around the world. Recently established programmes that focused on building One Health competencies and approaches have utilized top-down strategies, which rely on significant administrative buy-in and leadership. Other academic institutions have used a diversified funding model like the one used by UC Davis, where various public and private funding sources that support many smaller projects and programmes, build the OHI portfolio. Beyond any one project, a key to success has been shared respect and passion for the problems, the people, and the process of transdisciplinary problem solving around the world.

Developing 'One Health centres' with the aim of addressing a priority health issue using a transdisciplinary approach

Three case studies will be used to illustrate this approach. This includes two examples of One Health organizations that did not initially set out to be One Health organizations, the Centre for Coastal Health (CCH) and the Canadian Wildlife Health Cooperative (CWHC).

Case study 2. The Centre for Coastal Health (CCH).

The CCH was created in 1996 as a small, non-profit organization, before the term One Health was popularized. Its origins demonstrate the importance of cross-sectoral social networking in One Health. A medical health officer and a veterinary public health researcher were lamenting the challenges they had in working together on shared problems. No organization, programme or processes existed at the time to allow anything other than periodic projects to work in the One Health realm. These two individuals set forth to remedy this gap by creating a non-profit population health practice intended to bridge public health with animal health and the environment. When it began, no one contracted the CCH for One Health work, and few projects explicitly asked the organization to bridge or integrate considerations from one sector when trying to remedy health issues in another. As such, it was essential early in its formation that it demonstrated the value of cooperation and intersectoral practice. The CCH had to build the value proposition for what would be known as One Health at the same time as being able to help their clients solve pressing

Continued

Case study 2. Continued.

problems. This made it essential that the CCH: (i) was pragmatic and problem-solving focused, as opposed to being about discovery research; (ii) had leaders who understood the similarities and differences of management perspectives and priorities across sectors; and (iii) could show how cross-sectoral approaches made for more efficient or more effective solutions.

The CCH developed its One Health capacity iteratively. To foster collaborative approaches, it had to become commonplace for people from different sectors to come together to build trusting relations and commit to sharing what they knew. CCH staff developed skills to negotiate and translate priorities, perceptions and concerns across diverse sets of collaborators and stakeholders. This included collaborative approaches to aquaculture food security for poverty reduction that involved farmer collectives, government agencies and expertise from international development to work together on issues such as fish disease control and public health. As its reputation grew, it had to attract partners to widen its scope of understanding and build a firmer conceptual basis for its approach. The CCH became the focal point of a growing community of practice in the Canadian province in which it operated. It supported this community by enabling regional research networks and investing in developing cross-sectoral relationships, focusing first on groups that most frequently requested its services and then expanding to global networks and partnerships. This helped the CCH and those organizations it served to co-learn about how to match priorities and problems with perspectives and practices that would later come to exemplify One Health in practice.

Case study 3. The Canadian Wildlife Health Cooperative (CWHC).

The CWHC began as a network of veterinary pathologists in each of Canada's veterinary colleges. These wildlife pathologists saw value in sharing what they were encountering in their daily caseload to improve the understanding of the distribution and impacts of wildlife disease across Canada. The CWHC is an alliance of like-minded people, rather than an organization. Its legal status to receive and manage funds comes from its partner universities. These partners, in turn, provide a cost savings of almost 30% by providing infrastructure and part-time staff to address the CWHC mission. The return on this in-kind investment is more than doubled in terms of the research opportunities provided for faculty and graduate students from the CWHC operations, overhead fees received on grants and contracts received, and the links the CWHC brings the universities to the environmental pillar of One Health. Annual operations have been supported for over a quarter of a century from investment of over 30 government agencies in core surveillance functions and grants and contribution agreements to support risk management needs for conservation, public health and agriculture agencies. This funding model puts constant pressure on the CWHC to show its value, to individual sectors as well as cross-sectoral value.

The CWHC initially served provincial and territorial wildlife management agencies. When West Nile virus emerged in Canada and concerns about pandemic avian influenza grew, federal government agencies saw the expertise, network and information management capacity of the CWHC as critical parts of their emerging infectious disease response. The CWHC had to expand its scope of practice from diagnostics to risk management by asking 'Why did this die, what caused it and where is it?' and also 'Why does this matter and to whom'? Like the CCH (Case study 2), partnerships were essential to providing the breadth of understanding needed to translate findings from the wildlife disease realm into advice on risk management for public health, agriculture and conservation. As the political and management concerns over emerging infections abated, the CWHC had to maintain its relevance by including disease threat detection and provision of assurances of safety to build confidence in nature from its surveillance assessments. The CWHC leadership recognized that it could not secure sustainable funding on a disease-by-disease basis because: (i) social interest in diseases faded when the diseases went away, did not manifest their forecasted impacts or people habituated to their presence; and (ii) the focus on finding risks without concomitantly providing solutions reduced their value to already over-burdened management agencies. Public health agencies, among others, saw there was little that could be done to treat diseases in free-ranging animals and that the use of wildlife as sentinels was valuable but of limited public health value in a country where zoonoses were a minor public health concern. The CWHC leadership worked on changing the narrative from disease response to health protection through advocacy and strategic planning to and for its cross-sectoral partners. Holding no management or political power, the CWHC became a neutral party where individuals from various sectors could meet. It became a thought leader that helped its funders see needs and opportunities for wildlife health as a critical pillar of One Health programmes.

Many professionals associated with One Health or ecosystem health initiatives have extremely closely defined research or applied clinical skill sets. Given the skills needed to address messy problems using a One Health approach, transdisciplinary teamwork is required for their timely solution. The University of Saskatchewan has been receptive to the concepts of One Health and ecosystem health for many decades. The university has colleges for all of the major health-related professions, which is unique in Canada. Active collaborative research programmes using a transdisciplinary approach involving many academic units and research institutes continue to flourish, and both undergraduate and graduate teaching programmes focusing on the One Health concept have been developed in many academic units across the university.

In the field of veterinary toxicology, the focus is typically on agriculture and/or wildlife. Many toxicological problems directly impact the environment, and in some instances the human population. Animal or avian species, particularly wildlife populations, may serve as a sentinel for future human problems. For example, water contamination may become evident in fish or waterfowl before being observed in humans (Nguyen-Viet *et al*., Chapter 13, this volume). The toxicity of many pesticides used in the agriculture sector is well recognized by veterinary toxicologists, but poisonings are a rare event in humans. When suspected poisonings of this nature are observed in people, veterinary expertise is often a timely and essential resource. Viewing such a problem from different perspectives is therefore critical.

Case study 4. Toxicology Centre (University of Saskatchewan).

Approximately 25 years ago, several toxicology facilities in Canada established the Canadian Network of Toxicology Centres (CNTC). This network focuses primarily on toxicological research initiatives with national and international significance. The Toxicology Centre at the University of Saskatchewan provided the leadership in establishment of the CNTC. In association with the indigenous population in northern Saskatchewan, the university, with leadership from the Toxicology Centre, also established the Northern Ecosystem Toxicology Initiative (NETI). This is a unique interdisciplinary programme in toxicology, from which graduates have provided a steady source of highly qualified students for the graduate and research programmes.

The diverse talents related to One Health at both the University of Saskatchewan, and specifically within the Toxicology Centre, have enabled many of the clinical or diagnostic researchers to quickly solve unique and often rare disease outbreaks. Experts in agriculture, veterinary medicine, toxicology and the mining sector often provide an informed perspective that the front-line medical community can utilize to bridge species, regional or ecosystem barriers. Water quality, food safety and agricultural chemical use are broad examples. The synergism at the university, which has evolved over many years, has directly impacted the nature and intensity of One Health and ecosystem health research worldwide.

The examples cited below, emanating from the Toxicology Centre, are a unique mix of environmental and medical problems that often manifest in different ways depending upon the exposure circumstances. Inquiries from coroners involved in forensic investigations are often aided by expertise from the veterinary community, who encounter a different spectrum of toxins on a regular basis. The team approach often results in a successful investigation.

Strychnine poisoning

This is a common occurrence in the veterinary community but a rare event in the human population. In one incident in a person, strychnine was identified in tissue samples. The forensic investigation aimed to determine whether the poisoning was accidental, suicide or murder. Based on a discussion with the veterinary toxicologist, using analytical, circumstantial and pathological evidence, it was possible to determine the dose of strychnine, the time of exposure and death, and the person responsible for the murder. Without the combined team One Health approach this case may not have been solved.

Cyanide poisoning

Cyanide poisoning is a rare event in the human population, but is more frequently encountered in livestock poisoning incidents. In one clinical case involving a child, cyanide poisoning was suspected. The veterinary toxicologist was able to provide a rapid analysis of a blood sample to confirm the tentative diagnosis. Based on the colour of the blood, along with chemical confirmation,

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Case study 4. Continued.

cyanide was not the cause. The child lived in an agricultural community. During a brief discussion, it was determined that the child was exposed to a pesticide that is no longer available. The appropriate treatment was recommended, and the child made an uneventful recovery. Greater familiarity with this chemical by veterinary toxicologists enabled this child to recover rapidly without extensive testing and treatment.

Hydrogen sulfide

Hydrogen sulfide is an extremely toxic gas that is associated with sewage pits in the agricultural setting. Human poisonings are often tragic and fatal. In many instances, there are no witnesses to provide information, since all the affected persons die. A team effort between the veterinary community and the medical community using a One Health perspective often solves the mystery for this rapid and unfortunate event.

Building communities of practice and networks

The third way universities/research institutes globally are approaching capacity building in One Health/transdisciplinary research is through building communities of practice in ecosystems health/One Health. Based on a desire to develop opportunities to foster networking and knowledge exchange, articulated at the International Development Research Center (IDRC) Forum on Ecosystem Approaches to Human Health in 2003, a first community of practice was created in 2005 with the financial support of the Canadian Institutes of Health Research (CIHR) and the IDRC. Starting with a small group of scholars and practitioners who had collaborated together through the Québec-based Research Center Cinbiose, the Comunidad de Práctica sobre el Enfoque Ecosistémico en Salud Humana en América Latina y el Caribe (CoPEH-LAC) was founded. It brought together about 150 researchers, non-governmental organizations (NGOs) and policy makers from five regions (Mexico, Central America and the Caribbean, the Andean region, Brazil and the South Cone), fostering South–South collaboration, and from Canada, fostering South–North collaboration. The community of practice interaction is illustrated in Fig. 28.1.

The next 3 years saw the birth of other communities of practice: (i) Community of Practice for Ecohealth in the Middle East and North Africa region (CoPEH-MENA); (ii) Communauté de Pratique Ecosanté pour l'Afrique de l'Ouest et du Centre (COPES-AOC); and (iii) Canadian Community of practice in Ecosystem Approaches to Health (CoPEH-Canada). By 2008, many of these community members met at the International Ecohealth Forum in Mexico. Inspired by the community of practice model, but using another name, the Field Building Leadership Initiative was created in 2011 in South-east Asia (Fèvre *et al*., 2014). Finally, two of the communities of practice (CoPEH-LAC and CoPEH-Canada) created the Collaboration EkoSanté, to reinforce their existing collaboration. All these initiatives were financially supported, at least in part, by IDRC.

The relevance of communities of practice

Back in 2003, the concept of communities of practice, initially proposed by Lave and Wenger (1991), was to get momentum, both in academia and in business circles (Cox, 2005; Amin and Roberts, 2008; Storberg-Walker, 2008). This concept resonated with the thinking and practice of ecosystem approaches to health, which tends to favour a bottom-up approach, as well as close collaboration with local communities in order to achieve solutions (e.g. Parkes and Panelli, 2001; Waltner-Toews and Kay, 2005; Mertens *et al*., 2012). Largely missing from a conventional view of research-generated knowledge was that which comes from indigenous and local communities that have a deep and historical understanding of the many forces that determine their well-being and that of the living world around them. There was, and still is, little room in orthodox research institutions for informal, non-academic researchers as peers in collaborative programmes. The development of the community of practice model set out to change this paradigm by creating the necessary flexibility for knowledge co-creation and the acknowledgement of different voices, including that of local and indigenous communities, in the process (Berger-González *et al*., Chapter 6, this volume; Whittaker *et al*., Chapter 7, this volume).

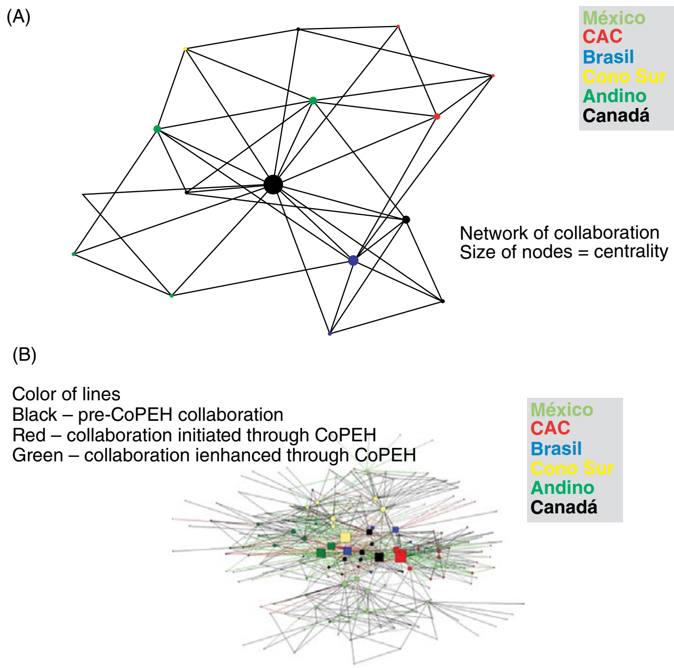

Fig. 28.1. Community of practice on ecosystem approaches to human health in Latin America and the Caribbean – growth from 2005 (A) to 2007 (B). CAC, Central America and the Caribbean; CoPEH, Comunidad de Práctica sobre el Enfoque Ecosistémico en Salud Humana.

Largely led by academia, grants were obtained to set up the communities of practice, meaning that grant holders from academic institutions had financial responsibility and control, a situation which was bound to create power inequalities and prevent the full participation of peripheral members. Two mechanisms were put in place to reduce this power differential. On the one hand, the core groups of experienced scholars leading the grant applications made sure to include younger colleagues in the process. On the other hand, and most importantly, the communities adopted a 'nodal structure': regionally based 'nodes' with great autonomy to conduct their activities (including financial decision making), with pan-national (LAC and EkoSanté) and national (Canada) projects and activities decided by a committee composed of node representatives.

Communities of practice, institutionalization and field-building

An important question in academia, as well as for funding bodies, is whether the communities of practice survive when the funding stops. According to Barab *et al.* communities of practice are 'a persistent, sustained social network of individuals who share and develop an overlapping knowledge base, set of beliefs, values, history and experiences focused on a common practice and/or mutual enterprise' (Barab *et al.*, 2004, p. 5). If this definition holds true, the ecosystem approaches to health communities described here have survived beyond the end of their funding – although in a different form. For example, CoPEH-Canada created a consortium of universities to support its ongoing activities, transforming its annual intensive course into a hybrid course with a pan-Canadian online part, combined with local fieldwork (Parkes *et al.*, 2017). COPES-AOC in Africa has developed a four-country joint-doctoral programme in ecosystem health, as well as an ecohealth Chair on Urban Air Pollution and Non-Communicable Respiratory Diseases, while EkoSanté has created an online 'expertise mapping tool' for scholars and practitioners to remain connected.

The contribution of these communities of practice to building the ecosystem approach to the health field is threefold: (i) relationship building; (ii) institutionalization; and (iii) support for emerging scholars and professionals.

BUILDING RELATIONSHIPS. The communities of practice have contributed to build relationships at various levels. Relationships between members of diverse communities of practice have connected communities, ensuring knowledge exchange and paving the ground for more collaborations. The presence of a Canadian node in CoPEH-LAC, the contribution of members of CoPEH-Canada to the Field Building Leadership Initiative (Fèvre *et al.*, 2014), the ongoing collaboration between the CoPEH-Canada 'east' node with COPES-AOC (Yates *et al.*, 2018), and the contribution of colleagues worldwide to the CoPEH-Canada teaching manual (McCullagh *et al.*, 2012) are tangible examples of outputs from these collaborations. Social network analyses conducted for CoPEH-Canada and CoPEH-LAC have revealed an increase in collaborations between members of the communities, many of which are still ongoing. Most importantly, collaborations between disciplines, countries (provinces) and domains of practice have increased significantly, indicating that the communities have indeed been a fertile ground for transdisciplinarity (Saint-Charles *et al.*, 2012; Saint-Charles and Rioux-Pelletier, 2013).

Finally, the communities have not developed in isolation from other groups and many of their activities have nourished conversations and collaborations between academia, community groups, governmental agencies and the private sector. Examples of such activities are: (i) the Ecohealth in Canada meeting series; (ii) the Talleres de Dialogo organized by EkoSanté; and (iii) the EcoHealth in Action activity organized during the 2014 EcoHealth Conference in Montreal. The latter was an interactive session during which the conference participants were immersed in the reality of local community groups and organizations, which, through their work, have built links between health, environment and society (Saint-Charles *et al.*, 2014).

INSTITUTIONALIZATION. While wishing to maintain a flexible structure, the communities of practice are aware of the necessity to foster the institutionalization of ecosystem approaches to health, as was exemplified by acknowledgement of ecosystem approaches to health as a milestone in population and public health research early in the life of CoPEH-Canada (Webb *et al.*, 2010). As the majority of members of the communities of practice come from academia, it is not surprising that most institutionalization work has been carried out in academic institutions, where structural and disciplinary barriers to this type of work persist. A common strategy has been the creation of programmes and courses, such as the CoPEH-Canada hybrid course, which was included on the course list of five universities. A research focus in the 'Sustainable Development' department of the University of Brazilia (Universidad de Brasilia) led to a mandatory course for doctoral students following a 'Climate, Health and Environment' research stream and master's students following an 'Environment, Society and Health' stream. Additionally, a module on ecohealth was included in the final year of studies for medical students at Universidad de las Américas (UDLA). Finally, memoranda of understanding have been signed between universities and like-minded groups such as Future Earth, the Global Health Coalition and the Sustainable Development Solutions Network, creating a more formal setting for collaboration, cross-fertilization and learning between like-minded organizations, individuals and communities.

SUPPORTING EMERGING SCHOLARS AND PROFESSIONALS. Supporting emerging scholars and professionals and including them in the communities of practice is critical. Support for younger colleagues should come in various forms, such as through fellowships and awards, training and capacity-building activities and, most importantly, through mentoring and advising. The EkoSanté fellowships and awards programme illustrated this diversity extremely well, in offering research fellowships that came with the support of at least two ecohealth mentors from different countries, travel awards to participate in the Canadian intensive course and EcoHealth Conference, grants to organize dialogue workshops with people from outside of academia, as well as professional development awards. The benefits for younger colleagues were numerous, including: (i) development of new relationships and the diversification of their networks through connections with other sectors, disciplines or countries; (ii) improvement of communication and language skills; (iii) strengthening of collaborative capacity; (iv) acquisition of new knowledge; and (v) changes in attitudes, values and practice (Parkes *et al.*, 2017).

Case study 5. Building One Health networks and communities of practice across the Caribbean region – 'One Health One Caribbean One Love'.

Caribbean nations are connected by shared waters, culture and climates, yet the distance, diversity and various approaches to governance between nations complicates efforts to promote an integrated, holistic approach to solving problems at the interface between human, animals and environmental health. Overcoming this challenge is urgent because of the many significant problems requiring a transdisciplinary or One Health approach in the region. Such problems include more frequent and more severe tropical storms and hurricanes (Gallagher *et al*., Chapter 24, this volume), water shortages, rises in sea levels, losses of fisheries, increases in mosquito-borne diseases and chronic non-communicable diseases linked to poor nutrition, poverty and environmental pollution. Taking these challenges and constraints into consideration, it is clear that the region needs to work together to address its shared challenges. This requires a transdisciplinary, intersectoral, One Health approach in which the connections between human, animal and environmental health are fully recognized and taken into consideration when carrying out interventions (Berger-González *et al.*, Chapter 6, this volume).

The University of the West Indies, along with various partner organizations including the Pan-American Health Organization (PAHO), Inter-American Institute for Cooperation on Agriculture (IICA) and the Food and Agriculture Organization of the United Nations (FAO), set out to address these issues through a European Union-funded project named 'One Health One Caribbean One Love'. This project aimed to both promote and roll out the One Health approach across the Caribbean region, making stakeholders aware of the need to follow such an approach and, in the process, give them the opportunity to use the One Health approach to address priority health issues in their home countries – a learning-by-doing approach.

A regional Caribbean One Health policy was prepared and approved by the Caribbean Community Ministers of Agriculture, Health and Environment, and a regional 6-year Caribbean One Health strategic framework to implement the One Health policy was written. Although policies and strategic plans are important, real change comes from the bottom up at a community level. To this aim, a core group of One Health leaders across 12 Caribbean countries was created, coming from multiple sectors (public, non-governmental and academic). Participants were carefully selected based on their leadership capacity, passion for One Health, and professional references. A multi-prong approach was used, combining themed training workshops (five in total), field trips, project formulation/management and reporting, and mentoring to foster leadership skills in the selected professionals. The workshops included technical training on One Health approaches, using concrete examples of successful One Health projects. The workshops also built leadership capacity, by setting personal goals and exploring leadership qualities, personality types, individual core values, and developing communication capacity. Team-building exercises were conducted in order to cement and sustain the Caribbean One Health Leadership team into the future.

Each country participant team also prepared a proposal for a simple One Health project addressing a priority health issue at the interface of human, animal and environmental health in their home country. Participants were encouraged to leverage additional funding. This activity gave participants the opportunity to practise project formulation and management, including reporting, as well as practical experience in developing and testing One Health approaches. Further details of each national One Health project, as well as other One Health-related projects being carried out in the region, have been published in a free e-book *Caribbean Resilience and Prosperity through One Health* (available at: http://www.cwhc-rcsf.ca/technical_reports.php (accessed 24 August 2020)).

Many lessons were learned throughout the project, including the importance of selecting project partners and affiliates with the political influence to ensure that the project had support from national governments, and who were willing to play active roles in achieving the objectives of the project. It was also critical to develop constructive working relationships with relevant stakeholders from the different countries taking part in the project, and to work with these stakeholders to ensure that the activities carried out in their countries had the highest possible impact. For the One Health Leadership series, it was important to ensure that the participants were actively interested, respected and engaged in the process both during the workshops and in the time between them. The importance of contracting informed, engaging and culturally sensitive facilitators, and that these facilitators played a leading role in developing the curriculum for the Leadership series, was critical, as was the need to maintain momentum in the time period between workshops through organization of relevant activities, discussions and webinars. It was also essential that participants had the full support of their line managers to complete the series. A rigorous selection process was, therefore, needed to ensure the quality and motivation of the participants. As for any workshop series, it was also extremely important to carry out detailed evaluations of all workshops in 'real time', to ensure that lessons were learned and applied to future workshops.

Funding One Health/Transdisciplinary Research Programmes in Academia – Challenges and Opportunities

Addressing the 'root causes' of ecosystem health problems using a transdisciplinary approach invariably exposes difficult and potentially disruptive understanding of the 'political ecology' (Brisbois *et al.*, 2017) of self-interested commercial and political forces that are driving the process of planetary instability. This defensive posture is largely due to the funding model that characterizes funding agencies mandated to provide the financial resources for research in the Global North. These agencies, both public and private, funded by national governments and philanthropists, are themselves internally divided into programmatic units with separate mandates and budgets. Their institutional structures reflect those of the universities, with separate faculties and departments defined by and channelled into distinct, conventional narrowly defined disciplines, focused on defining and protecting their domains and unwilling or unable to pursue 'root cause' research. Many of these kinds of initiatives are poorly funded. The only time adequate funding appears is after a disaster, which most often is too late, as the damage is done and the losses or diseases cannot be reversed. Unfortunately, this is how many government agencies work worldwide. There is therefore a real need for funding agencies and governments to take a more proactive, rather than a reactive, approach to funding ecosystem health problems going forward (Gallagher *et al.*, Chapter 24, this volume).

Research funding agencies may therefore play a critical role in promotion of a more transdisciplinary research culture across academia in future. One can imagine a visionary funding agency issuing a call for proposals for research on the impact of mining operations in the Southern Cone of South America (Birn *et al.*, 2018). As a fully integrated research programme, it would examine issues such as: (i) the geological structures of mineral deposits; (ii) the commercial value of those deposits; (iii) the cultural and political determinants of indigenous opposition to mining operations; (iv) the impact of these operations on natural and artificial water systems; (v) their ultimate effects on mosquito populations increasing risk for transmission of Zika virus; (vi) the political influence of foreign (Global North) mining companies on corrupt practices both in the zone of operations and in their home countries; and (vii) the destruction of stable ecosystems leading to higher frequency of encounters between humans, previously remote wildlife and exotic infectious pathogens (e.g. Ebola virus).

Into which academic department or faculty would such a call be directed? If any one component of this complex scenario were excluded from the study or neglected, the results would be incomplete and would not lead to policy or action to solve the complex economic, health and environmental challenges posed by mining operations. If a progressive research funding agency launched a call for such an integrated approach to address this complex problem, it is entirely possible that an equally progressive research institution might respond by creating a space (perhaps temporary, but not another department!) for the researchers to work collaboratively, non-competitively and productively – for instance, where geologists and anthropologists work side by side with political scientists, computer scientists, economists, biologists and indigenous leaders from affected regions.

Through the bureaucratic structural separation of the many facets of global health research for development, the perpetuation of fractured and ineffective programmes is virtually guaranteed, and missed opportunities for fully integrative, non-disciplined research focused on problem solving and finding solutions will be obvious. Progressive research funders that have no conflicted or vested interest in the status quo (Hall and Sanders, 2015) should take up the challenge of leading and driving change in our research institutions. This has the potential of bringing about meaningful and sustainable improvement in the health of humans and the ecosystems that sustain us.

Conclusions

Building research capacity using a transdisciplinary or One Health approach in universities and academic institutes around the world is extremely challenging from both an organizational and cultural perspective, however, it also represents an extraordinary opportunity. Many 'structural' and 'cultural' barriers still need to be broken down in academia to enable this approach to be successfully implemented. A remaining challenge facing One Health is establishing the same kind of inter-professional relationships with the biological, and especially the ecological community, as those evolving among the traditional health sciences. In the latter case, there have been decades of collaboration between veterinary and human medicine, even if not at an optimal level. Building functional bridges between the traditional health sectors and the biological and social science communities that have a vested interest in ecosystem health and sustainability, is challenging. However, this chapter illustrates some real and concrete examples showing where and how this is happening.

Whether using an 'umbrella' approach, such as in the UC Davis One Health Institute, or using the 'transdisciplinary centre' model based around a specific theme or problem, universities are providing the environment that is necessary for multiple people from different faculties, organizations and communities to work together. Playing a leading role in the development of communities of practice, linking academia with the communities that they serve also enables academic institutions to broaden their research portfolios through gaining a deeper understanding of the many forces that determine the well-being of communities and the living world around them.

In academia, incentives are often the best way to get people out of their silos and starting to think in new ways. These could be financial incentives related to grant funding opportunities, or career-building incentives related to gaining opportunities for promotion. Changing the way that research in academia is funded is therefore critical to the whole process of developing a more transdisciplinary approach to research, as academics and researchers are driven by funding opportunities that are available to them. If funding bodies demand that a transdisciplinary approach is implemented to address a particular health problem, then that is what they will get, as researchers will do what they are funded to do. However, in order to convince funders of the benefits of advocating a One Health or ecosystem health approach, they need to see evidence that this approach is advantageous over more traditional approaches (Zinsstag *et al*., Chapter 31, this volume). This has been the main challenge facing the One Health community. Resources are needed to approach problems in a transdisciplinary way to provide the working examples, but resources are hard to acquire without evidence that the approach is likely to be fruitful. We need to see a creative sea change in how funders go about funding this type of work and convincing relevant government agencies (funding and otherwise) is a major component to sustaining these new approaches.

Acknowledgements

Thanks to Ole Nielsen and David Waltner-Toews for providing advice and significant input to the chapter.

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29 One Health in Policy Development: Options to Prevent Rabies in Cattle in Bhutan

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Introduction

Bhutan is a small, landlocked Himalayan kingdom located in South Asia, between China to the north and India to the south, west and east. About 60% of its population (estimated at 750,000) live in rural areas and depend on agriculture and livestock farming for their livelihoods. As a result, livestock remains critical to enhancing and sustaining rural livelihoods. With the country's aim to attain self-sufficiency in livestock products, the Royal Government of Bhutan prioritized improvement of livestock productivity, including dairy cattle. Besides ensuring accessibility to breed improvement programmes by establishing artificial insemination centres and supplying breeding bulls across the country, the government also provides subsidies to import exotic breeds of cattle, mostly from India, to supplement the supply of improved cattle breeds within Bhutan. Because of this, the number of farmers rearing exotic breeds of dairy cattle, mainly European breeds such as Jersey, have been increasing. For instance, the percentage of imported cattle breeds increased from 24.1% in 2012 to 27.4% in 2014 while the indigenous cattle (*Bos indicus*) decreased from 75.9% in 2012 to 72.6% in 2014 (MoAF, 2015). As rural communities are dependent on cattle and other livestock species for their livelihoods, infectious diseases such as rabies, brucellosis, anthrax and leptospirosis not only reduce productivity and result in death of animals, but also pose a significant public health risk. Whereas all livestock diseases have a potential impact on rural communities, some have more immediate impacts. Rabies, due to the high case fatality rate in exposed individuals and the potential public health risk, remains a disease of great concern. Although dog-mediated rabies has been successfully eliminated from most regions of Bhutan, it remains endemic in the southern parts of the country (Tenzin *et al*., 2012a). Sporadic incursions are also reported in the east (Tenzin *et al*., 2017). Elimination of rabies from the southern part of Bhutan is complicated by the porous border with the neighbouring Indian states of West Bengal and Assam. Dogs are the main reservoir for rabies in Bhutan and it is thought that wildlife-transmitted rabies is currently not a significant consideration in the region. Further work may be needed to fully assess this in the future. Around 17 outbreaks of rabies are reported annually in dogs with spill-over infection to other domestic animals, resulting in continuous public health risks and economic losses (NCAH, 2017). There has not been a human case of rabies reported in the country since 2016.

Statistics from the National Centre for Animal Health (NCAH) indicate that cattle are the most frequently affected livestock in the rabies endemic areas of Bhutan. In 366 outbreaks reported between

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1996 and 2017, the most frequently reported were in cattle (51%), followed by dogs (41%), cats (2%), horses (1.7%), goats (1.6%), pigs (1.4%) and sheep (0.2%) (Tenzin *et al.*, 2019). Rabies cases in dairy cattle potentially lead to claims of mass exposure in humans, largely due to consumption of products from rabies-suspected cattle (CDC, 1999; Tenzin *et al.*, 2010b). Requests from the public for post-exposure prophylaxis (PEP), related to potential exposure to rabid cattle or their products, may occur where there is delayed identification and reporting of cattle cases due to the lack of knowledge about the clinical signs in cattle and uncertainty about transmission risk. Annually it is estimated that around 10% of people receiving PEP for rabies in Bhutan are subsequent to consumption of meat and dairy products derived from cattle confirmed to have died of rabies (Tenzin *et al.*, 2012b). The Royal Government of Bhutan currently spends an average of 9 million Bhutanese Ngultrum (BTN) (US$142,000) annually to provide PEP to potentially exposed individuals (Penjor *et al.*, 2019). In the National Rabies Prevention and Control Plan, it is recommended that cattle demonstrating signs of rabies should be quarantined, euthanized and subsequently tested (NCAH, 2017). As Bhutan is predominantly a Buddhist country, pre-emptive culling of exposed cattle based on risk assessment is a difficult option to undertake, although cattle can be quarantined until death occurs naturally. If cattle have a history of being bitten by a rabid dog, and clinical signs have not developed, the current control plan recommends that the veterinarian undertake post-exposure prophylactic treatment in cattle (NCAH, 2017).

The current government rabies control policy facilitates the implementation of an effective and coordinated rabies control programme in the dog population. As a result, there is currently no general directive for broad implementation of pre-exposure vaccination for rabies in cattle (Rinchen, 2018). This chapter describes the complex issue of handling rabies cases in cattle in Bhutan and illustrates the value of taking a cross-sectoral One Health approach to developing policy options.

One Health in Bhutan

Globally, there is growing acceptance that taking an interdisciplinary cross-sectoral approach is essential if we want to address the complexity of emerging human, animal and environmental health problems (Zinsstag *et al.*, 2012; Cork *et al.*, 2016). While the concept of 'One Health' has recently gained momentum at the global level, in Bhutan there has long been a well-integrated and coordinated mechanism for prevention and control of zoonotic diseases. This was further strengthened during the outbreak of highly pathogenic avian influenza (HPAI) in 2003 in South-east Asia. At this time, the Department of Public Health (DoPH) under the Ministry of Health (MoH) and the Department of Livestock (DoL) and Bhutan Agriculture and Food Regulatory Authority (BAFRA) under the Ministry of Agriculture and Forests (MoAF), collaborated to carry out a joint risk assessment. This was followed by successful delivery of a World Bank-funded National Influenza Preparedness and Response Project and development of the National Influenza Pandemic Preparedness Plan (NIPPP). Implementation of the NIPPP led to rapid containment of 13 HPAI outbreaks in poultry, with the first outbreak in February 2010 effectively controlled using a One Health approach. The MoAF (DoL and BAFRA) and MoH (DoPH) subsequently collaborated on development of further guidelines and plans for prevention and control of zoonotic diseases such as rabies, anthrax and scrub typhus (McKenzie *et al.*, 2016). Currently, a One Health approach is used to investigate and respond to any outbreak of zoonotic disease in Bhutan (see Table 29.1).

Two ministries (MoAF and MoH) collaborated on the development of the Bhutan One Health Strategic Plan (2017–2021) which was formally approved by the government in 2017 (MoAF and MoH, 2017). Subsequently a memorandum of understanding was signed between MoAF, MoH and other collaborating partners, including the National Environment Commission (NEC), the Ministry of Home and Cultural Affairs and academic institutions (Royal University of Bhutan and Khesar Gyalpo University of Medical Sciences of Bhutan), in November 2017 on the eve of World One Health Day. A proposal for formal establishment of a One Health Secretariat is currently being pursued in the country (Fig. 29.1). This will probably be based at the Royal Centre for Disease Control (RCDC) near to the capital city Thimphu.

The MoAF and MoH also collaborated on the launch of a series of national One Health conferences to sensitize human and animal health personnel, and other stakeholders, to the concept of One Health and promote multisectoral coordination

Table 29.1. Guidelines and disease prevention and control plan documents for zoonotic diseases jointly developed by Ministry of Agriculture and Forests (MoAF) and Ministry of Health (MoH).

Name of guideline or disease prevention and control plan	Year
National Influenza Pandemic Preparedness Plan for Human Health Sector	2009
Guidelines for Preparedness, Surveillance and Control of Anthrax in Human and Animals in Bhutan	2013
National Guidelines for Management of Rabies and Anti-rabies Prophylaxis in Bhutan	2014
National Influenza Pandemic Preparedness Plan for Animal Health Sector	2014
National Rabies Prevention and Control Plan	2017
Bhutan One Health Strategic Plan 2017–2021	2017
Strategic Plan for Elimination of Dog-mediated Human Rabies in Bhutan by 2030	2019

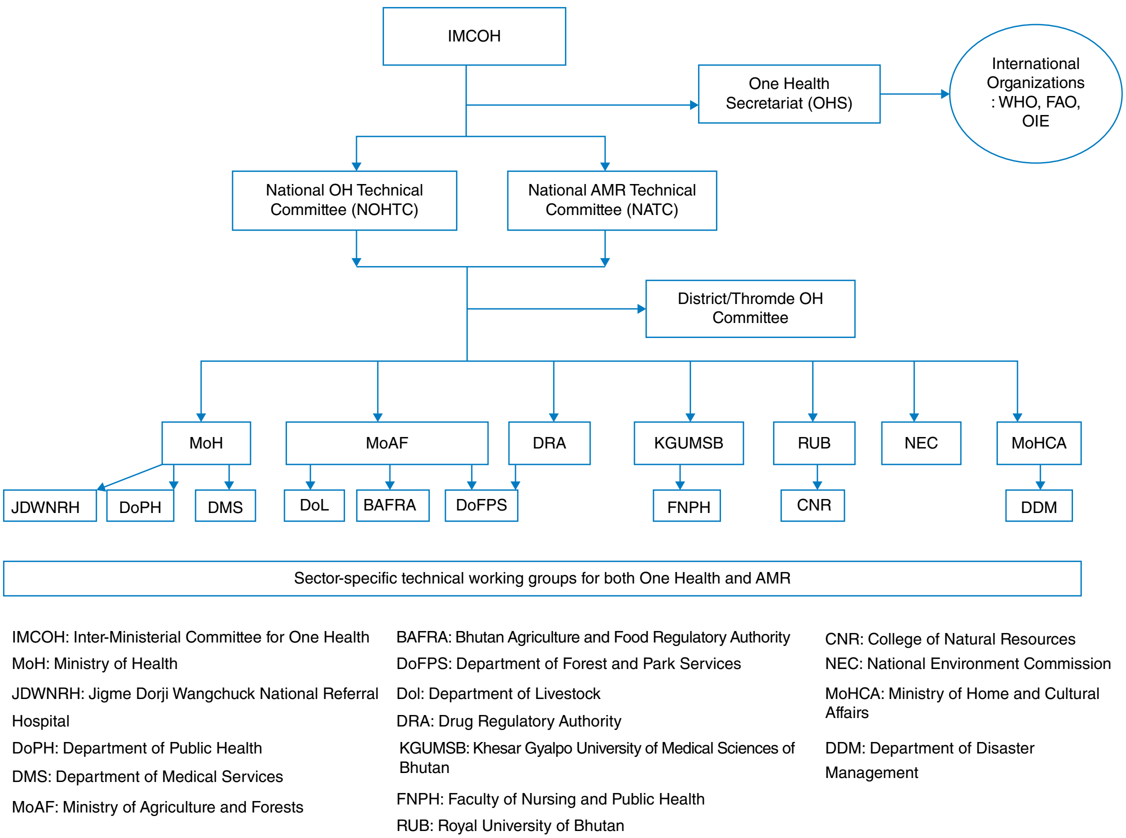

Fig. 29.1. Institutional arrangement for One Health in Bhutan. AMR, antimicrobial resistance; FAO, Food and Agriculture Organization of the United Nations; OH, One Health; OIE, World Organisation for Animal Health; WHO, World Health Organization.

and collaboration at the national, regional and district level.

Other recent initiatives include a European Union (EU)-funded One Health training programme. As part of this, six human and animal health professionals from Bhutan were given the opportunity to pursue master's studies in collaboration with Massey University, New Zealand. The programme facilitated several collaborative One Health research projects in Bhutan and neighbouring countries (McKenzie *et al.*, 2016). The two ministries were also successful in acquiring a

Fleming Fund Country Grant on Antimicrobial Resistance (AMR) from the UK Government, Department of Health and Social Care. This project is expected to improve surveillance for AMR in both the human and the animal health sectors. In addition to the country grant, the Fleming Fund also awarded seven fellowships to provide continuing professional development and leadership training opportunities.

Research to Inform Policy

Bhutan has proactively supported several collaborative research projects to inform the development of the National Rabies Prevention and Control Plan. Several studies have been conducted on the epidemiology of dog-mediated rabies in Bhutan, assessment of the economic impact, molecular characterization of virus isolates, and an assessment of community knowledge, attitude and practice associated with the control of rabies in dogs (Tenzin *et al*., 2019). These studies have built on, and complement, work done in other countries (Zinsstag *et al*., 2009, 2017). However, despite cattle being the most frequently infected livestock species, no study had previously been conducted to explore options to prevent rabies in cattle or mitigate the associated economic losses and public health risks (Rinchen, 2018).

Currently, a common problem faced by human health physicians in Bhutan is to rationalize use of PEP. There may be pressure to provide PEP even where the risk of exposure to live virus is likely to have been very low. For example, PEP may be demanded by a large number of people with a history of drinking the milk from or handling or dressing cattle subsequently found to have died of rabies. During such occasions, especially where there is uncertainty about the likelihood of exposure, a large number of people may be provided with PEP, and the subsequent cost to the government is substantial. To date, there has not been a significant shortage of PEP available to physicians in Bhutanese health clinics, but this might not always be the case. It is recognized that allocation of scarce resources would need to be determined using case-by-case risk assessment. As a result, a key area of research identified was to better assess the public health risks associated with exposure to rabid cattle or following consumption of products derived from presumptive rabid cattle.

While the risk associated with consuming well-cooked meat and pasteurized milk is considered to be negligible, transmission of rabies from consuming raw meat and milk remains theoretically possible (CDC, 1999). It is reported that dressing the carcasses of animals that have died of rabies and handling rabid animals, including cattle, can potentially be a source of infection in humans. For example, Wertheim *et al.* (2009) reported two separate cases of human rabies after butchering, processing and consuming a suspected rabid dog and cat in Vietnam. It is, however, not clear if the infection occurred from the oral route or due to contact between infectious fluids with damaged mucous membranes or abraded skin while dressing the carcass. Similarly, Tariq *et al.* (1991) reported a case of rabies in a butcher who died after skinning a calf that had previously expressed neurological signs. Cases of rabies in animal health workers and animal owners following handling of rabid animals have been reported from Brazil and Iran (Brito *et al*., 2011; Simani *et al*., 2012). In a review of non-bite rabies transmission, Afshar (1979) reported rabies transmitted to a lamb nursed by an experimentally infected ewe. It is possible for the virus to access mammary tissue and subsequently to be excreted in the milk. A study carried out in India demonstrated presence of viral RNA in the milk of rabies-suspected cows (Dandale *et al*., 2014). The World Health Organization (WHO) states that drinking raw milk from a rabid animal, although not advised, does not result in exposure to rabies virus and thus PEP is not advised (WHO, 2018). However, in rabies endemic countries where rabies is highly prevalent, low-risk exposures associated with rabies in cattle often place physicians under pressure, especially where community members demand PEP. It is clear that, in addition to considering the technical aspects of rabies prevention and control, it is also important to understand the cultural perspectives, the level of understanding and behaviour of community members because lack of public engagement in the development and delivery of disease control programmes is frequently a key barrier to success. Further research on this aspect is required (Rinchen *et al*., 2019).

Current Government Policy for Rabies

Government policy for rabies control in Bhutan currently encourages a One Health approach, as described later in this chapter. Key factors for considering and evaluating the One Health approach are described by Zinsstag *et al.* (2015a,b,c) (see also Zinsstag *et al.*, Chapter 2; Schelling and Hattendorf, Chapter 8; Häsler *et al.*, Chapter 10; Zinsstag *et al.*, Chapter 31, all in this volume). Rabies is a notifiable disease for both human and animal health sectors in Bhutan. The DoL currently oversees the rabies control activities in the country. Management of zoonotic diseases, including rabies, is listed in both the Livestock Act of Bhutan 2001 and the Livestock Rules and Regulation 2017. The National Rabies Prevention and Control Plan (NCAH, 2017) specifies the detailed plan of action including the roles and responsibilities of various stakeholders for prevention and control of rabies. Rabies prevention and control in the country is also emphasized in the National Dog Population Management Strategy (MoAF, 2019) and Bhutan One Health Strategic Plan 2017–2021. The Human Rabies Management Guideline 2014 covers aspects of dog bite management, rabies case management, reporting for surveillance and standard recommendations for rabies PEP in humans. Recent assessment of rabies control using the 'Stepwise Approach towards Rabies Elimination' (SARE) tool was done in September 2017 and May 2019, revealing a score of 3.5/5 indicating that rabies in animals is under control and the country is gearing towards an elimination phase (Fig. 29.2). Based on this assessment, Bhutan developed a Strategic Plan for Elimination of Dog-mediated Human Rabies by 2030 (MoAF and MoH, 2019).

Bhutan is the first country in Asia that has committed to the 'United Against Rabies' collaboration (a collaboration between the Food and Agriculture Organization of the United Nations (FAO), the World Organisation for Animal Health (OIE), WHO and the Global Alliance for Rabies Control (GARC)) to eliminate dog-mediated rabies by 2030 (WHO, OIE, FAO and GARC, 2018). Under the zero by 30 global strategy plan, there are Start up (2018–2020), Scale up (2021–2025) and Mop up (2026–2030) phases of the rabies elimination plan. Bhutan is included in the Start up phase as one of 29 countries to demonstrate successful elimination of rabies. Aligning the current rabies control programme to the goal of zero by 30, the government emphasizes mass dog vaccination, awareness education, and availability and accessibility of PEP to humans exposed to potential rabid animals.

Practical workplan towards Achieving Rabies Elimination

NATIONAL WORKPLAN SUMMARY - Bhutan - 2019

SARE Score **3.5**	Years to rabies elimination **7**

Phase	SARE Stage	Estimated Timeline	Completed
Assessment	0 to 1	--	Completed
Strategic Planning	2	--	Completed
Control	3	Years 1, 2 and 3	Ongoing
Elimination	4	Years 4 and 5	Ongoing
Maintenance	5	Years 6 and 7	Ongoing

Fig. 29.2. Stepwise Approach towards Rabies Elimination (SARE) assessment score for Bhutan.

Control of rabies in dogs

Dogs are the primary reservoir of rabies in Bhutan, and there is a large population of free-roaming and stray dogs which travel freely across the southern border. Cross-border transmission of rabies poses an ongoing risk of the virus spreading into interior rabies-free areas of the country due to the large size of the dog population. In 2016, Bhutan had a total dog population of 119,624 (71,245 owned dogs and 48,379 free-roaming dogs) (Rinzin *et al.*, 2016). Since mass dog vaccination is a cost-effective and proven tool for elimination of canine rabies virus, the current government policy aims to achieve > 70% vaccination coverage supported by dog population management through a programme called Catch-Neuter-Vaccinate-Release (CNVR). The government procures canine rabies vaccine and occasionally has supplies donated by the OIE through OIE Vaccine Bank.

As part of the Animal Birth Control programme, free-roaming dogs are caught on the street by trained dog catchers and taken to clinics where they are neutered and vaccinated against rabies. Between 2009 and 2019, about 105,000 dogs and cats were neutered and vaccinated against rabies under the CNVR programme (Tshedup, 2020). Annual mass dog vaccination campaigns are routinely carried out to create an immune buffer along the southern border. In addition, owned dogs are vaccinated annually on World Rabies Day (28 September) or when presented at animal health centres located across the country. In some areas, the vaccination coverage is low (about 30%) due to logistical challenges to catch and vaccinate large numbers of free-roaming dogs. It was estimated that 57% vaccination coverage had previously been achieved in two rabies endemic towns in southern Bhutan (Tenzin *et al.* 2015).

Rabies education

Awareness education on rabies is crucial to ensure that the public are aware about the disease, its public health implications and available risk mitigation options. Further, as the public play a critical role in any disease control programme, awareness campaigns are important in garnering community support to implement effective disease control activities. Currently, information on rabies is disseminated in several ways. At the sub-district level, livestock extension officers conduct training programmes in which awareness on rabies is imparted to communities (Fig. 29.3). Every year on the 28 September, coinciding with the World Rabies Day, awareness education is disseminated to a diverse target group through road shows, walkathons, and rabies talk and quiz programmes in schools. Further, in collaboration with the Bhutan Broadcasting Service (BBS), radio programmes and rabies videos are broadcast to disseminate information on rabies and other zoonotic diseases. In a recent study conducted among 562 cattle owners in the selected rabies endemic and rabies non-endemic areas of Bhutan, the most reported source of rabies information was neighbours (315), followed by formal news media (122), animal health training programmes and rabies awareness campaigns (113), family members (58), schoolchildren (45) and the Internet (8) (Rinchen *et al.*, 2019).

Early reporting and rapid response

Use of smartphone and social media apps played an important role in ensuring timely reporting of rabies and other disease outbreaks in Bhutan. Suspected cases of rabies and other notifiable diseases are mostly reported by community members to the nearest animal health centres. Upon a preliminary investigation, the suspected outbreak is reported to the district, regional and national level through use of a flash reporting system, e-mail and phone call. The flash reporting form is a one-page form that contains the details of the outbreak, such as species and number of cases, owner's name, farm or place name, date of outbreak, suspected source, number and population at risk and the intervention measures undertaken at the local level. Once an outbreak is confirmed, a rapid response team, comprised of members from the DoL, DoPH, BAFRA and other relevant stakeholders, is formed to contain the outbreak (NCAH, 2017). However, challenges regarding effective response to rabies outbreaks remain, largely due to limited resources – both financial and human resources – and the difficult terrain of the country.

Change of the rabies PEP protocol in humans

The production and use of nerve tissue vaccine (NTV) was phased out in all South Asian countries. Bhutan discontinued use of NTV in 1996 and replaced it with human diploid cell culture vaccine.

Fig. 29.3. Rabies awareness education programme conducted in a rabies endemic area of Bhutan.

In 2013, the country introduced the lower cost but equally effective updated Thai-Red Cross intradermal rabies vaccine regimen. The MoH is in the process of further updating the PEP regimen that requires the patient to visit a clinic only three times and complete the course in 1 week (WHO, 2018).

Rabies prevention in cattle

In Bhutan, vaccines for most livestock diseases are provided free of cost by the government. However, cattle and other livestock species are not routinely vaccinated against rabies, as there is no government policy supporting pre-exposure vaccination. The current rabies control programmes in Bhutan are focused on mass dog vaccination that requires at least 70% coverage of the dog population to interrupt transmission among dogs (Coleman and Dye, 1996). However, endemic areas in Bhutan are faced with ongoing cross-border transmission associated with the movement of free-roaming rabid dogs.

The OIE recommends vaccinating cattle and other livestock species in rabies endemic areas (OIE, 2020). A preliminary economic analysis indicated the benefit of vaccinating cattle in the high-risk areas within the rabies endemic areas of the country (Rinchen, 2018). This should be supplemented with improved management practices such as proper housing of animals, enhanced monitoring during rabies outbreaks, rapid containment of outbreaks, and further awareness education on rabies for cattle owners (Rinchen *et al*., 2019). However, a more comprehensive study including further assessment of the economic benefits of the pre-exposure vaccination in cattle is required to make a sound policy decision.

Post-exposure treatment options in cattle

Post-exposure treatment is provided to domestic animals including cattle following exposure to a suspected rabid dog bite injury. However, this requires early detection of bite incidents, identification of the bite wound, immediate first-aid measures including thorough washing of the bite wound with soap and water followed by appropriately administered PEP (NCAH, 2017). It is reported that early detection and prompt treatment has saved several animals during rabies outbreaks in eastern Bhutan. The current Essen regimen practice of administering 1 ml of rabies vaccine intramuscularly on days 0, 3, 7, 14 and 28 may be replaced with the modified Essen regimen of administering 3 ml, 3 ml, 2 ml, 1 ml, 1 ml on days 0, 3, 7, 14 and 28, respectively. Using this modified Essen regimen resulted in high protective virus neutralizing antibody titres of 1.243 IU/ml, 8.905 IU/ml, 27.5 IU/ml and 52.5 IU/ml on days 3, 7, 14, 28 post-vaccination, respectively, and elicited higher antibody level when compared with the standard Essen regimen in cattle (Abraham, 2019). PEP in animals is also practised in other countries (Manickama *et al*., 2008; Wilson, 2010).

Cross-border harmonization

Except for islands and countries surrounded by difficult geographical features (e.g. the rugged terrain of the Himalayas) cross-border transmission of disease remains an ongoing challenge. Any country that shares a contiguous and porous land border with a rabies endemic country is constantly facing risk of new incursions (Gongal and Wright, 2011). One of the major challenges in Bhutan's effort towards elimination of rabies from its territory is the transboundary transmission of rabies associated with cross-border movement of free-roaming dogs between rabies endemic areas of Bhutan and neighbouring states in India. A need for regional cooperation in implementing parallel disease control programmes among the regional member states has been emphasized at various regional meetings (Gongal and Wright, 2011).

Challenges to Rabies Control

Bhutan aims to achieve zero dog-mediated human rabies deaths by 2030. However, there are several challenges that the country must overcome in achieving this goal (MoAF and MoH, 2019).

Rabies diagnostics

Having an adequate and reliable diagnostic capacity to detect and confirm cases of rabies is an important component of an effective rabies control plan. This remains a constraint in many rabies endemic and resource-poor settings. Bhutan currently has a robust rabies surveillance programme and good access to diagnostic services which are provided through a network of veterinary staff and veterinary laboratories. Laboratories at the district and regional level have the screening capacity to test for rabies using rapid diagnostic test kits while the confirmatory diagnosis of rabies, using the gold standard fluorescence antibody test (FAT), is done at the NCAH near Thimphu (Tenzin *et al*., 2020). The FAT was also established in one regional laboratory in the eastern part of the country. Previously, having to send all suspect samples for confirmation to NCAH increased the turnaround time and therefore the risk of disease spread and human cases. Further development of the veterinary diagnostic system is likely to be considered as more advanced technology becomes available. Although the current system is functional, there remain logistical challenges and constraints with regard to financial and human resources.

Uncertainties around providing PEP in self-reported atypical exposures

In Bhutan, PEP is provided free of cost to exposed individuals. As outlined earlier in this chapter, the cost to the public health sector further escalates when PEP is provided to 'mass exposure' cases. The level of PEP provided by the human health sector is determined by the category of bite wound (category I, II and III). The highest-risk category (III) is also provided with hyper-immune serum, as recommended in the current WHO guidelines (WHO, 2018). Whereas the guidelines for handling cases of dog bites are well established, the approach to dealing with cases of atypical exposure to rabies is less clear, especially where there remains a level of uncertainty around risk. Decisions depend on a number of factors including the clinical discretion of the human health practitioner.

Porous border

Currently, only the areas that share a border with the neighbouring states of India regularly report rabies (Fig. 29.4). Whereas there are regulations regarding the cross-border movement of livestock, it is difficult to regulate movement of free-roaming dogs in these areas. Recognizing the value of vaccinating dogs on both sides of the border, the DoL has undertaken targeted sterilization and vaccination of dogs on the other side of the border. However, Bhutan is a resource-limited country and funding activities to undertake rabies control across the border is not a sustainable approach. Currently through cross-border harmonization meetings at the local level, a platform is being created to share ideas and resources to deal with the complex problem of transboundary animal diseases in the region. There is an urgent need to develop a sustainable mechanism for cross-border rabies control activities on both sides of the border.

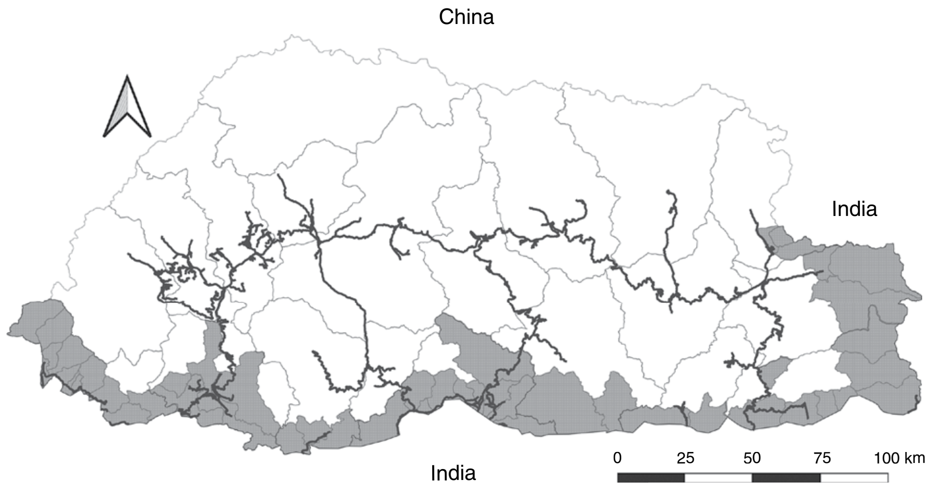

Fig. 29.4. Rabies endemic areas of Bhutan (shaded areas in the map) and the four national highways (black lines) connecting rabies endemic and non-endemic areas.

Increasing free-roaming dog population

Dogs are an integral part of the Bhutanese culture and are widely accepted in Bhutanese communities. They live closely with the people and feed on kitchen waste and leftovers. These factors facilitate breeding and contribute to the growing free-roaming dog population. Other sources of free-roaming dogs include owned dogs allowed to roam freely and owned dogs that are abandoned by their owners. A study found that about 16% of free-roaming dogs were actually owned in two southern Bhutanese border towns, Phuentsholing and Gelephu (Rinzin *et al*., 2016). The unique and complex relationship between the dogs and communities in Bhutan contributes to the growing free-roaming dog population and also poses a potential risk for the spread of rabies. The DoL, with support from relevant stakeholders, continues to implement the CNVR model to control the free-roaming dog population but this is a resource-intensive exercise. It is recognized that there needs to be broader collaboration among various stakeholders to ensure proper waste management and responsible pet ownership.

In view of ensuring effective management of the dog population in the country, the National Dog Population Management (DPM) Strategy was recently launched (MoAF, 2019). The strategy will reinforce the DPM programme at the national, district, municipal and sub-district levels, and ensure effective collaboration between the relevant stakeholders.

Current cattle-management practices

Vaccination of cattle against rabies was discussed above. Additionally, exposure risks can be reduced by minimizing contact between cattle and free-roaming dogs, by reducing free grazing, fencing pasture land and providing proper animal housing. However, in a study conducted by Rinchen *et al*. (2019), about 70% of cattle owners (n = 562) reported having only a temporary shed or no shed for their cattle while the majority of them (86%) reported practising extensive or semi-extensive grazing, where cattle are freely grazed with little monitoring. Although there are financial incentives (e.g. access to building materials for shed construction) to change cattle-rearing practices on the outskirts of larger towns (Wangchuk *et al*., 2014), deep-rooted farming practices of free-grazing cattle, compounded by a farm labour shortage, will continue to pose challenges in bringing positive change in cattle-management practices.

Risk of rabies introduction into rabies-free areas

The western, central and northern regions of Bhutan have not reported any rabies outbreaks for almost two decades. However, the trend towards increasing human settlement along highways in Bhutan connects rabies endemic and rabies-free areas and facilitates overlap of dog home ranges. The latter enables interaction of free-roaming dogs and may provide an ideal environment for sustained dog-to-dog transmission of rabies and expansion into non-endemic areas (Rinchen *et al*., 2020). Rabies incursion into the rabies-free areas of Bhutan, resulting from distant movement of rabid dogs, has been reported in the past (Tenzin *et al*., 2010a,b). In these outbreaks, dog-to-dog transmission along the road networks is believed to have sustained the spread of rabies. Similar instances of dog-mediated rabies spreading along highways and human dwelling areas is reported elsewhere (Waltner-Toews *et al*., 1990; Bamaiyi, 2015). Therefore, it is vital to extend dog vaccination programmes into areas adjacent to the rabies endemic areas to prevent infection and spread in the susceptible dog population.

In addition, rabies can be introduced through human-mediated movement of pet animals. For example, recently a case of rabies in a dog imported from India was reported from Haa, a town in the non-endemic north-western region of Bhutan (Tenzin, 2016). Although the Livestock Rules and Regulation of Bhutan 2017 stipulates a valid permit for import and movement of pets within the country, outbreak investigation revealed that the pet owner was not aware of the import permit requirements. This incident underlines the need to sensitize animal/pet owners about the existing rules and regulations regarding animal movement and their importance to achieving maximum compliance. Further, the risk of rabies reintroduction into a rabies low-risk zone through pet animals can be mitigated by enhancing inspection for illegal movement of pets at the check posts along highways. Several incidences of human-mediated translocation of rabid dogs from rabies endemic areas to canine rabies-free countries have been reported (Castrodale *et al*., 2008; Ribadeau-Dumas *et al*., 2016). Given the global move towards zero by 30, reintroduction of rabies into rabies-free territories would be a huge setback and thus remains a significant concern.

Conclusion

By taking a One Health approach, the Government of Bhutan established a leading role in tackling emerging infectious diseases in humans and animals in the region. As a result, Bhutan has successfully eliminated rabies from most parts of the country. This was achieved through sustained mass dog vaccination, backed by strong policy support, and effective community education programmes. Bhutan was the first country in Asia to commit to the 'United Against Rabies' goal to eliminate dog-mediated human rabies by 2030 (WHO, OIE, FAO and GARC, 2018), and current control programmes have been aligned to achieve this target. In developing effective rabies control plans, Bhutan also faces the challenge of responding to rabies infection in cattle and other livestock species. Ultimately, this will depend on elimination of rabies in the dog population. Achieving rabies control in cattle is challenged by free unregulated movement of dogs across the porous border especially in the south and parts of eastern Bhutan. At the present time, enhanced control of rabies in cattle could be achieved by targeted vaccination of cattle in the high-risk areas of the country as well as enhanced farmer education, changes in cattle management and less extensive grazing during rabies outbreaks. However, in view of the increasing number of rabies cases reported in cattle, and the important role that cattle play in sustaining rural livelihoods, there is a need to continue efforts to control rabies in dogs with a concurrent effort to improve livestock management.

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30 One Health into Action: Integrating Global Health Governance with National Priorities in a Globalized World

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In this chapter we review the evolution of global health governance (GHG), from the early years of international health diplomacy in the 19th century, to a discussion of the systems, actors and networks that currently hold a stake in GHG today. Through describing the changing relationships between health policy and practice, the authors explore and provide an analysis of the various options, considerations and challenges that may be required to sustainably operationalize One Health on a global scale in the future.

Challenges of Health Governance in a Globalized World

Introduction

GHG in the 21st century has been defined by the rising stake of 'non-traditional health actors' (Clark *et al*., 2010) in a sphere previously dominated by a limited number of key actors including the World Health Organization (WHO), the World Organisation for Animal Health (OIE), some bilateral partnerships and several key research institutes. Globalization, re-emerging disease threats, the rise in philanthropic initiatives by private companies and individuals, international pressure to achieve the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs) have all been credited with generating increased visibility and funding for global health issues within the political sphere in recent years. Moving into the third decade of the 21st century, the need to understand and communicate the potential benefits of One Health practices within a broad range of rapidly changing health governance contexts is growing.

Mapping the pathways of international health diplomacy from the 19th century illustrates several similarities and challenges faced by previous international health actors, many of which remain pertinent to global health today. By examining the evolution of health policy and governance into – and beyond – the 20th century, valuable lessons can be drawn as regards how to navigate the current 'explosion' of often-competing donors, systems and policy narratives that define contemporary GHG

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networks. Examining the trajectory of the WHO since 1948, in light of its 'global political legitimacy' (Clark *et al.*, 2010), provides insight into the interconnections, alliances and priorities that have formed within and between the major health actors since the formation of the United Nations (UN), and within which One Health must become embedded. However, there have also been increasing questions raised since the 2013–2016 Ebola outbreak in West Africa that have challenged the broader structure of GHG – and indeed the WHO's legitimacy within this space – in recent years. Given the impact of severe acute respiratory syndrome (SARS) on the International Health Regulations (IHR), only time will tell what the next 5–10 years will bring in the wake of Ebola and the current global health challenge of COVID-19.

The rise of a global public goods (GPGs) perspective as a means to 'solve' world health problems is also pertinent in light of the 'broad consensus' that One Health is a public good (CDC and EU, 2011). In terms of infectious disease control, One Health principles align well with a key component of GPGs theory: the promotion of international collective action, a political process which ensures the benefits of controlling a disease within one's country are maintained in the absence of 'free-riding' by other nations (Smith, 2003; Smith *et al.*, 2004; Zinsstag *et al.*, Chapter 31, this volume). However, some have argued that GPG theory has 'fuelled the proliferation of specific infectious disease-targeted programmes' (Smith and MacKellar, 2007). Promoting One Health as a GPG could therefore inadvertently encourage the recent explosion of vertical approaches to health challenges, such as seen with the international response to highly pathogenic avian influenza (HPAI), conflicting with wider philosophies surrounding horizontal and more holistic approaches to health outside a crisis situation. Furthermore, addressing global health concerns through various health security and/or trade policy narratives may not be key priorities in developing countries that have limited access to global markets, and where pressure to prioritize domestic health issues such as HIV/AIDs, malaria and tuberculosis often overwhelm national health budgets. An analysis of options that may serve to motivate and encourage developing countries to invest in alternative One Health approaches is essential.

Globalization and GHG

Globalization is defined as the process of increasing social, economic and political interdependence; recognizing that events in one part of the world have an ever-growing effect on people and places in another (Fidler, 2001). Globalization evolves as people, goods, concepts, capital, ideas and values diffuse across national borders, with 'critical implications for public health and global health governance' that affects sustainability of health systems worldwide (Taylor, 2002). However, for many sectors globalization is a double-edged sword, as mass flows of people, animals, goods and services across borders ensure that health determinants, status and outcomes can no longer be guaranteed solely by the actions of individual national governments. This realization drives the current discourse around international collective action that urges health actors to look beyond government sectors to include various private and third-party actors in order to better manage the growing health risks associated with globalization. It has been argued that the effects of globalization may ultimately undermine sovereignty, resulting in changes to traditional health governance whereby nation states are forced to adopt innovative transnational strategies that engage both state and non-state actors, in order to ensure the health of their own country (Ng and Ruger, 2011). External non-health influences can also impact on human, animal and environmental health determinants within a country or region, such as transportation systems, trade, migration (legal and illegal), illicit activities, communication technologies and environmental destruction. Globalization is perceived to amplify such issues, further depleting the extent to which individual nations can fairly, responsibly and sustainably tackle health issues alone (Lee and Pang, 2014). Indeed, the term 'global health governance' has evolved from questions surrounding the ways in which human populations can better meet their increasing collective health needs; loosely defined as 'the agreed rules, processes and institutional arrangements for achieving collective health needs across populations and geographies' (Lee and Pang, 2014).

The first 100 years of international health governance: 1851–1951

International platforms for public health diplomacy have been in place, in some form, since the 19th century and examining the history of international health governance can provide important lessons that may guide 21st-century decisions (Fidler, 2001).

For example, although quarantine practices in Europe can be traced back to the 14th century (Bell *et al*., 2010) *international* cooperation for control of global risks to human health did not emerge until the mid-19th century. Original shifts from national to international governance evolved largely as a response to increasing public health threats from infectious disease, opium and alcohol, transboundary pollution and occupational hazards at the time.

The first International Sanitary Conference occurred in 1851, when European states gathered to discuss cholera, yellow fever and plague. National quarantine policies in place at the time had become compromised, largely due to technological advances in transportation such as improved rail networks and faster ships, with cholera in particular becoming an important emerging infectious disease of the 19th century (Fidler, 2001).

Following the first International Sanitary Conference, a number of 'global' public health initiatives were established; nation states adopted treaties, staged conferences and created international health organizations with various mandates to facilitate cooperation on infectious disease control (Table 30.1). Science took a lead role in informing policy and treaty development; for example advances in germ theory established by Koch and Pasteur (Fidler, 2001). There followed a rapid expansion of initiatives and actors in international health cooperation, particularly for infectious disease, with the private sector playing a major role in exerting pressure on states to cooperate on laws and policies for the control. Several non-governmental organizations (NGOs) including the Rockefeller Foundation and the International Union against Tuberculosis became instrumental in supporting and developing international treaties and laws. By 1951, this movement had resulted in the creation of five international health organizations, the International Sanitary Regulations (a precursor to the IHR, Box 30.1) and the OIE Codes for animal health (Box 30.2).

Notably, veterinary physicians became early pioneers of transnational response mechanisms for highly contagious and deadly infectious diseases in animals that ultimately led to a similar concept of cross-national coordination of human health services (Bresalier *et al*., Chapter 1, this volume). There are two drivers for this, first animal health actors must often consider the needs of a population over the needs of individual, and secondly, the economic impact of animal diseases is a potentially large, and often a highly visible, threat. Rinderpest for example, has been of global economic importance since its emergence in Egypt in 3000 BC, with efforts for control beginning in earnest in the 18th century. The unexpected emergence of rinderpest in Belgium in 1920, from a shipment of Zebu cattle transiting in Antwerp en route from India to Brazil, was the motivation for 28 pioneer states to sign an

Table 30.1. International treaties for human infectious diseases 1892–1951. Adapted from Fidler, 2001.

Year	Treaty
1892–1912	Series of seven International Sanitary Conventions (including one Pan American Sanitary Convention)
1924	Pan American Sanitary Code
	Agreement Respecting Facilities to be Given to Merchant Seaman for the Treatment of Venereal Disease
1926	International Sanitary Convention, modifying the 1892–1912 International Sanitary Conventions
1927	Additional protocol added to the Pan American Sanitary Convention
1928	Pan American Sanitary Convention for Aerial Navigation
1930	Convention Concerning Anti-Diphtheritic Serum
	Agreement regarding measures to be taken against Dengue
1933	International Sanitary Convention for Aerial Navigation
1934	International Convention for Mutual Protection Against Dengue Fever
1938	International Sanitary Convention, amending the 1926 International Sanitary Convention
1944	International Sanitary Convention, modifying the 1926 International Sanitary Convention
1944	International Sanitary Convention for Aerial Navigation, modifying the 1933 International Sanitary Convention for Aerial Navigation
1946	Protocols to Prolong the 1944 International Sanitary Conventions
1951	International Sanitary Regulations, subsequently renamed (in English only) the International Health Regulations (IHR) (1969)
1995	World Health Assembly agrees to revise and update the IHR (1969)
2007	IHR (2005) enter into force on 15 June 2007

Table 30.2. Agreements made by the World Organisation for Animal Health (OIE) (1924–2014). Adapted from OIE, 2014.

Year	Treaty
1924	International agreement – 28 states – creating the Office International des Epizooties
1928	Geneva conference establishing the basis for an international sanitary police
1952	Agreement with the Food and Agriculture Organization of the United Nations (FAO) – created in 1951
1960	Agreement with the World Health Organization (WHO)
1993	Agreement with the Inter-American Institute for Cooperation on Agriculture (IICA)
1998	Agreement with the World Trade Organization (WTO)
1999	Agreements with the Organismo Internacional de Sanidad Agropecuaria (OIRSA) and the Secretariat of the Pacific Community (SPC)
2000	Agreement with the Pan-American Health Organization/World Health Organization (PAHO/WHO)
2001	Agreement with the World Bank
2002	Agreements with the Organization of African Unity – Inter-African bureau for Animal Resources (OAU-IBAR), the World Veterinary Association (WVA), the International Federation for Animal Health (IFAH) and various others
	New agreement with WHO
2004	New agreement with FAO
	Exchange of letters with the European Commission
	Agreements with the Andean Community and various others
2005	Agreement with the General Secretariat of the South Asian Association for Regional Cooperation (SAARC) and various others
	At the Geneva conference of 7–9 November, National Veterinary Services are recognized as a public good
2006	Agreement with the Arab Organization for Agriculture Development (AOAD)
2007	Agreement with the Economic Community of West African States and five others
2008	Agreement with the International Council for the Exploration of the Sea (ICES), the International Air Transport Association (IATA), the Inter-American Development Bank (IDN), the African Economic and Monetary Union (WAEMOU), the International Poultry Council (IPC) and the International Council for laboratory Animal Science (ICLAS)
2009	Cooperation agreement with the WAEMU
2011	Agreement with the International Council for Game and Wildlife Conservation (CIC), the Arab Maghreb Union (AMU), the International Organization for Standardization (ISO) and the World Small Animal Veterinary Association (WSAVA)
2012	Agreement with the United Nations Office for Disarmament Affairs (UNODA), the International Union for Conservation of Nature and Natural Resources (IUCN), the Caribbean Community (CARICOM) and the Commonwealth Veterinary Association (CVA)
2014	90th Anniversary of the creation of the OIE, recalls its 90 year commitment to Standards, Transparency, Expertise and Solidarity, with a base of 180 member states
2015	The Assembly adopted the OIE's 6th Strategic Plan for the period 2016–2020

international agreement creating the Office International des Epizooties, known today as OIE; 27 years before the creation of the UN (Table 30.2). Within the European Union (EU), animal health has been a full community competence for a considerable period of time, with attempts to harmonize animal health legislation starting as early as 1957. In contrast human health, even after the Maastricht and Lisbon Treaties, remains mostly a national competence.

The global health situation a century ago 'exhibited the same paradox as has been identified by contemporary analysis of the globalization of public health' (Fidler, 2001). States, non-state actors and international health organizations need to be realistic as to what may be accomplished through international law and other policy templates alone as a means for tackling global health issues.

State consolidation of the numerous sanitary conventions of the 19th and 20th centuries resulted in a single set of rules; officially named the International Health Regulations 1969. The IHR are updated to reflect major changes in the world health picture, for example smallpox eradication in 1981, and are the only *legally binding* set of international rules on infectious disease control for all 194 WHO member states. The current IHR (2005) was endorsed by the Fifty-eighth World Health

Assembly (WHA) in May 2005 to better reflect 21st-century threats such as emerging infectious diseases and other public health emergencies such as nuclear meltdowns. IHR (2005) entered into force on 15 June 2007.

Shifting influence of the WHO from the 1950s 'international health diplomacy' to the GHG of the 21st century

Since the inception of the WHO in 1948, tensions between socio-economic and technical approaches to health care, and the systems for its delivery, have been defined by shifting global politics and dominant international actors (Brown *et al*., 2006). The role of the WHO as 'unquestionable leader' in international health was severely challenged towards the end of the 20th century (Godlee, 1994; Brown *et al*., 2006; Lidén, 2014), and again during the 2013–2016 Ebola crisis in West Africa (Mackey, 2016); only time will tell how well the WHO has handled the current COVID-19 coronavirus outbreak. Understanding the changing role of the WHO since its formation in 1948 serves to provide a background to the current global health contexts within which One Health finds itself today.

Box 30.1. International Health Regulations (IHR) (2005) of the WHO.

To prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade.

(WHO, 2019)

Early years of WHO (1940s and 1950s)

The concept of permanent institutions for world health trace back to 1902 with the Pan American Sanitary Bureau, which eventually became the Pan American Health Organization (PAHO). In 1907, the Office international d'hygiène publique (OIHP) was mandated with the overall administration of the international sanitary agreements. In 1923, the Health Organization of the League of Nations established its offices in Geneva, extending the work of the OIHP through supporting international disease commissions via epidemiological intelligence and technical reports. The formal establishment of the WHO constitution occurred on the 7 April 1948, incorporating the OIHP, the League of Nations Health Organization and the Health division of the UN Relief and Rehabilitation Administration. Early indications of possible tensions between the European health actors and the

Box 30.2. The Codes of the OIE.

The OIE, recognized by the Sanitary and Phytosanitary (SPS) Agreement is implementing its mission with various instruments. The most prominent ones are the Animal Health Codes.

The two OIE Codes are the International Animal Health Code (for terrestrial animals: mammals, birds and bees) and the International Aquatic Animal Health Code (for fish, molluscs and crustaceans). The Codes, and their associated Manuals, are designed as reference documents to be used by the veterinary administrations (or competent authorities) of OIE member countries to assist the establishment of regulations around the import and export of live animals and animal products in order to avoid or minimize the spread of pathogens responsible for diseases to other animals or to humans. In addition to recommendations specific to diseases, the OIE has also developed general principles relating to risk analysis methodology, comprised of four components, namely: (i) import risk assessment; (ii) assessment of veterinary services; (iii) zoning/regionalization; and (iv) surveillance and monitoring.

As scientific knowledge on disease agents and their ways of diffusion increase daily, new diagnostic techniques become available, and control methods become more refined, the OIE Codes and Manuals are revised. For development of OIE recommendations, the procedures within the OIE encourage the active participation of countries in drawing up the rules that will apply both to others and to themselves. These recommendations are established by consensus by members' chief veterinary officers.

The standards of OIE have also proved an important reference point for dispute settlement mechanisms of the World Trade Organization (WTO) (WTO, 2014).

USA were evident however, when the PAHO opted to remain autonomous in the Americas in the interest of 'national security' (Brown *et al.*, 2006).

African independence and shifting world power relations (1960s and 1970s)

The 1960s and 1970s saw emphasis on socio-economic reforms, attributed to independence from former colonial powers and the spread of socialist movements such as the civil rights movement in the USA. Unlike the World Bank and other large agencies where national votes are weighted according to financial contribution, all member states of the WHO share an equal vote in the World Health Assembly (WHA). The broadening WHO agenda during this period is largely attributed to this increase in WHO member states – by the late 1960s, Latin American, Asian and African states held over two-thirds majority in the WHA (Walt, 1993). WHO's technical mandate had largely spared it the 'political conflicts wracking the rest of the United Nations', but the new demands of health systems in developing nations was the beginning of WHO's 'key role' in international health policy (Godlee, 1994; Brown *et al.*, 2006).

WHO in crisis (1980s and 1990s)

The 1990s saw a rise in publications in prominent journals that both questioned and affirmed the role of the WHO, reflecting the wider dialogue at the time (Walt, 1993; Godlee, 1994; Lee *et al.*, 1996; Vaughn *et al.*, 1996; Silver, 1998; Yach and Bettcher, 1998). Extra-budgetary funding overtook that from WHO member states for the first time in 1991 (Table 30.3) resulting in the World Bank, the United Nations Development Programme (UNDP) and wealthier nation states 'largely calling the shots' through a series of vertical programmes (Walt, 1993). For example, the 1993 launch of UNAIDS (Joint United Nations Programme on HIV/AIDS) effectively removed WHO's largest budget from its control (Godlee, 1994), while the 1990 Children's Vaccine Initiative proposed by UNICEF (United Nations Children's Fund), UNDP, Rockefeller and several others was seen by the WHO as nothing less than an 'attempted coup' on the WHO (Brown *et al.*, 2006). Demands for the international health agenda to align with donor interests led to 'a cycle of decline, with donors expressing their lack of faith in its central management by placing funds outside the management's control' (Walt and Gilson, 1994).

Former Norwegian Prime Minister Dr Gro Harlem Brundtland was appointed WHO Director-General in 1998, with an aim to revitalize and reposition WHO as a key actor in global health (Kickbusch, 2000; Lidén, 2014). Stakeholders from the private and non-governmental sectors were brought together with governments and other agencies to strengthen WHO's financial position, expanding extra-budgetary funding and leading to an explosion of public–private partnerships in what has been termed the 'global health decade' (Hotez and Fenwick, 2009). Some have attributed this to the 'longer standing trend towards the private' as a result of World Bank structural adjustment programmes, while others credit it directly to the new direction taken by WHO under Brundtland (Williams and Rushton, 2011). Between 1998 and 2003 health became a 'central theme' on the international political agenda, with a myriad of externally funded health partnerships, alliances and philanthropic organizations such as the Bill & Melinda Gates Foundation rising in prominence; by 2005 over 70 international partnerships had been created.

Table 30.3. Shifting trends in WHO extra-budgetary funding 1950–2011.

Year	WHO budget member states (US$ millions)	Extra-budgetary funding (US$ millions)
1950	6	0
1971	75	< 25
1986–1987	543	437
1990–1991	654	770
1998–1999	842	956
2002–2003	830	1500
2010–2011	945	2900

Further loss of WHO's traction in global health matters (2003 onwards)

Despite the positives, reports of 'unease and some tension' at the decreasing financial importance, and thus influence, of traditional health actors were beginning to surface in the early 21st century, for example the concern that spending on global health by the Bill & Melinda Gates Foundation in 2007 was almost equal to WHO's annual budget for the same year (Clark *et al.*, 2010). These new global health initiatives (GHIs), formed largely under Brundtland's leadership (e.g. UNAIDS; Gavi, the Vaccine Alliance; PEPFAR; Stop TB Partnerships;

and The Global Fund to Fight AIDS, Tuberculosis and Malaria), have also been challenged by concern that they have the potential to support parallel health systems and bypass traditional international governance structures (Mackey, 2016). Alongside this, the technical mandate of the WHO, historically its strongest advantage, was slipping away as 'new' global health actors gained traction and confidence in their expertise on health matters, for example the US President's Emergency Plan for AIDS Relief (PEPFAR) sought expertise from American academic institutes and NGOs rather than from the WHO (Lidén, 2014). Moreover, the perceived disconnect between the national health ministries that govern the WHA, and those responsible for financing for health issues, appeared to be growing, challenging WHO's ability to reform and provide the much-needed direction and leadership of the global health agenda (Lidén, 2014). This has not been helped by the fact that during these years, more development-oriented UN agencies such as UNDP and UNICEF have increasingly been accused of 'taking the initiative' on health, likely a result of persistent budget limitations from within WHO that have led to a continued reallocation of resources from normative functions to discretionary programmes highly influenced by donors (Mackey, 2016).

2013–2020: the West Africa Ebola epidemic and COVID-19; a turning point for WHO?

The Ebola outbreak of 2013–2016 resulted in a further severe challenge to the WHO's public image, being described as WHO's 'do or die' moment, with pressure to reform from several groups (Moon *et al.*, 2015). While calls to reform the WHO were not new at the time, it is undeniable that 'the voices have grown incessantly louder' in recent years (Checchi *et al.*, 2016; Mackey, 2016; Yach, 2016). It has been suggested that institutional innovation – rather than reform – is the only way that the WHO can be fit for purpose further into the 21st century (Smith and Lee, 2017); COVID-19 will perhaps be the ultimate test of how open WHO actually is to reform.

One Health's Increasing Political Traction in the 21st Century

From HIV to SARS: early drivers for One Health

The emergence of high-profile emerging disease threats such as bovine spongiform encephalopathy (BSE), SARS and H5N1 HPAI in the early 2000s helped propel what was at the time the relatively new concept of 'One Health' into the centre of global health policy dialogue (Zinsstag and Weiss, 2001; Zinsstag *et al.*, 2005). Securitization describes the politicization (in relation to security concerns) of an issue that was previously not a major issue for the public, or at least not a reason to fear; a 'model that explains the transition by which an issue such as influenza can be moved from the non-political sphere to the political sphere, and ultimately into the realm of security' (Collins, 2007). Securitization of a topic demands a combination of two key elements: (i) the voice of a credible authority; and (ii) the belief of the listeners.

The health security narrative has emerged frequently in recent years – particularly in the context of emerging infectious diseases and One Health. However, the notion of controlling disease in another country for the benefit of one's own has existed for much longer. A speaker at the third session of a joint WHO/Food and Agriculture Organization of the United Nations (FAO) meeting on malaria in 1948 claimed: 'Africa cannot be fully exploited, because of the danger of flies and mosquitoes; if we can control them the prosperity of Europe will be enhanced' (Packard, 1997). Similar views were expressed during the 1950s and 1960s, with the belief that health improvements in developing countries would expand markets for US goods (Packard, 1997). Malaria control was used as a political tool for 'wining hearts and minds' of underdeveloped nations in the war against communism (Brown *et al.*, 2006). Towards the end of the 20th century, health became increasingly conceptualized as 'a limited resource to be defended'; US President Bill Clinton famously stated that infectious diseases such as HIV posed 'a threat to US national security because of its catastrophic social consequences, particularly in the developing world' (Leboeuf and Broughton, 2008).

Framing global health narratives around health security can have both positive and negative impacts on how a health issue is managed, both by politicians and the implementers of health policy. For example, the high-profile 'fear narratives' in the early years of the HIV/AIDS epidemic resulted in a large amount of advocacy and resources; including the creation of a specific UN agency (UNAIDS), explicit reference in the MDGs, and debate at the UN Security Council (Leboeuf and Broughton, 2008). However, those working at the community level to 'normalize social perceptions' of HIV/AIDS in many countries viewed this approach to disease control through the 'narrow framework of security' as detrimental to HIV-positive individuals, 'wrongly identified as the risk rather than the referent object' (Elbe, 2006; Collins, 2007). The same could be said for any high-profile disease; the unprecedented human quarantine efforts currently in place to contain COVID-19 highlights the difficult balance between the health rights of the nation versus the health rights of its individual citizens in the era of globalization.

One Health Case Study 1: SARS in 2003 – the 'nail in the coffin' for conventional international health governance

SARS was the first zoonotic epidemic of the globalized 21st-century society, and is widely considered to have permanently changed the way in which global health is governed. SARS was a new disease and therefore not subject to the IHR (Fidler, 2004) and the global impact of the disease demonstrated how epidemiological information in a globalized world does not respect sovereignty. When the Chinese government showed reluctance to openly report on the magnitude of the problem in China, WHO relied on innovative approaches to gain epidemiological information, including the media, the Internet and individual case reports. Previous restrictions on external international agencies to 'dictate' outbreak control measures in the name of sovereignty were overruled, with the WHO demonstrating an unprecedented power over nation states at the time (Fidler, 2004; Lidén, 2014). Ethical issues also arose during management of the SARS outbreak: for example the balance of professional duty with fears for personal safety, economic losses against containment of disease and other balancing acts required to ensure public health while simultaneously protecting human rights (Singer *et al.*, 2003; Fidler, 2004).

Perhaps, however, the biggest outcome from the SARS epidemic was the recognition that the WHO's IHR were in need of an 'urgent update' (Mackey, 2016), culminating in a renewed version – the IHR (2005) – being approved in 2007 (WHO, 2019). This revision of the IHR now required member states to commit a minimum standard of public health system function that incorporated laboratory capacity, surveillance and emergency response mechanisms (Mackey, 2016). The call for the move from 'exclusive self-evaluation' to external evaluation comes from a distinct recognition that 'transparency and mutual accountability in the international community are essential in implementing IHR collectively' and in 2015 a technical consultation meeting on the IHR Monitoring and Evaluation Framework suggested the development of the WHO Joint External Evaluation (JEE) tool (WHO, 2019). The other addition under the new IHR (2005) was a legal requirement for member states to proactively report potential international disease events, regardless of whether it was a 'novel' disease or not, giving WHO the power to declare a 'public health emergency of international concern' (PHEIC) (Mackey, 2016).

One Health Case Study 2: the global response to avian influenza (GRAI) and subsequent formation of the FAO-OIE-WHO Tripartite

The global response to avian influenza (GRAI) was based on a political initiative launched at the first International Ministerial Conference on Avian and Pandemic Influenza (IMCAPI) in Beijing, January 2006, triggered by the EU. The GRAI was founded on strong ad hoc collaboration and joint leadership of the EU, the USA and the United Nations System Influenza Coordination (UNSIC) Office, who in collaboration with the World Bank, the OIE and relevant UN agencies, developed policies and set up mechanisms for the crisis response. The GRAI benefitted from two closely related drivers. The first was the process of securitization of previous sanitary crises, largely due to SARS but also from weaknesses in responses to several natural catastrophes (e.g. the heatwave in France in summer 2003 and Hurricane Katrina in the USA in August 2005). The second was the rapid set up of partnerships directed against H5N1, including strong leadership from the EU and the USA that together contributed the political driving force for broader networking from individual countries, the UN, the OIE and the World Bank.

A major outcome of the GRAI has been the successful, sustained coordination at the international level between political stakeholders, development partners, UN agencies and the OIE. While WHO's relationship with the FAO has been at times strained, particularly regarding the priority given to veterinary public health, the GRAI was instrumental in building strong alliances between these UN agencies, for example through promoting alliances between the OIE and UN agencies to develop the

Global Early Warning System (GLEWS), that built on the added value of combining and coordinating alert mechanisms for WHO, FAO and OIE. Similarly, while the OIE took some time to consider whether embarking on a One Health path was realistic and appropriate, the organization's subsequent commitment to One Health (2008 onwards) also helped to amplify collaboration across the global network of the veterinary services to promote One Health as a means to address issues such as food safety, food security, antimicrobial resistance, climate change and the human–animal bond. The outcome of these collaborative actions has resulted in the unprecedented WHO/FAO/OIE tripartite partnership (the Tripartite) that promoted integration of foodborne, neglected zoonotic and tropical diseases within the One Health movement. These partnerships, originally established through the GRAI, have provided a firm foundation for the development and application of One Health approaches globally, further translated into strategies and policies at sub-national levels (Okello *et al*., 2014).

In 2010 the Tripartite (FAO, OIE, WHO) published a concept note on sharing responsibilities, collaboration and coordination of global activities, and integration of control systems for disease control. This concept note acknowledges that while integration has been attempted in some countries, there remains limited collaborative work in the control systems of many countries (FAO, OIE and WHO, 2010). This led to the Tripartite High-Level Technical Meeting (HLTM) of 2011 in Mexico, providing a platform for stakeholders to discuss priorities at the human–animal–ecosystem interface within the One Health vision (USAID, United Nations System and World Food Programme, 2011). The HLTM identified three technical topics – rabies, zoonotic influenza and antimicrobial resistance – to showcase the importance of multi–sectoral collaboration to address risks at the human–animal–ecosystem interface. Since then, a number of initiatives have reinforced the Tripartite's commitment to these three technical areas, including a High Level Technical Meeting in Antimicrobial Resistance (September 2016), a global rabies conference (December 2015) and the support of greater collaboration between the OIE/FAO Network of Expertise on Animal Influenza (OFFLU) and the WHO Global Influenza Surveillance and Response System (GISRS) (FAO-OIE-WHO, 2017). More recently, the 2017–2020 strategic vision of the Tripartite outlines several additional areas of focus and technical support in addition to those areas identified at the HLTM in Mexico, including food safety, health systems strengthening and research and development for issues in human health, animal health and food safety (FAO-OIE-WHO, 2017).

One Health Case Study 3: Ebola outbreak 2013–2016

The first death from the West African Ebola epidemic occurred in December 2013; the ensuing chain of events led to over 11,000 deaths, and once again brought the threat of emerging viral zoonoses to the world's attention. The Ebola epidemic exposed 'deep inadequacies' in the GHG framework (Moon *et al*., 2015) and spurred various analyses of the global emergency health response system since then (Checchi *et al*., 2016). Examples include the Independent Panel on the Global Response to Ebola, jointly launched by the Harvard Global Health Institute and the London School of Hygiene and Tropical Medicine, which concluded that 'major reforms are both warranted and feasible' with a road map of ten interrelated recommendations across four thematic areas (Moon *et al*., 2015). In addition, the WHO Executive Board established an Interim Assessment Panel established by the WHO Executive Board (Interim Panel), the US National Academy of Medicine led the Commission on a Global Health Risk Framework for the Future (CGHRF) and the then UN-Secretary General Ban Ki-Moon appointed a High-Level Panel on the Global Response to Health Crises (Kikwete Panel) to propose recommendations that would strengthen national and international systems to prevent and respond effectively to future health crises, taking into account lessons learned from the Ebola response (Mackey, 2016).

Much like the SARS epidemic a decade earlier, the Ebola outbreak once again resulted in deep questions that 'extend to the very foundation of how we approach governance for global health in the 21st century' (Mackey, 2016). Several suggestions have been put forward in recent years as to alternative governance arrangements, particularly during outbreak responses, that allow for the formal sharing of the complex responsibilities of health security to other international structures, for example a UN Global Health Panel chaired by WHO but housed within the UN Economic and Social Council (ECOSOC) (Mackey, 2016); the current outbreak and subsequent PHEIC declaration around COVID-19 may be the turning point for such radical reform.

One Health as an Opportunity for Broader Efforts at Health Systems Strengthening under the SDGs

(i) Integrating existing tools for monitoring and maintaining capacity in global health: the WHO JEE and the OIE Performance of Veterinary Services (PVS)

As part of the IHR (2005) Monitoring and Evaluation Framework, the WHO JEE was developed as a mechanism to independently assess a country's core capacity in public health, as assessed by a group of international experts. The JEEs are voluntary, collaborative and multisectoral external assessments that aim to assess a country's progress in achieving the targets under Annex 1 of the IHR, recommending priority actions to be taken across 19 technical areas of evaluation. External evaluations are seen as part of a continuous process of strengthening capacities for the implementation of the IHR, and to date, over 79 countries have participated.

In contrast to the relatively recent development of WHO's JEE tool, the OIE PVS Pathway is a long-standing global capacity-building platform for the sustainable improvement of national veterinary services. The PVS Pathway seeks to empower national veterinary services by 'providing them with a comprehensive understanding of their strengths and weaknesses using a globally consistent methodology based on international standards – a useful external perspective that can reveal gaps, inefficiencies and opportunities for innovation' (OIE, 2019). Similar to the JEE, the OIE PVS Pathway is a multisectoral, voluntary and collaborative process that takes a long-term approach to the sustainable development of national veterinary services.

It is acknowledged that PVS Pathway reports have the potential to align and facilitate the JEE, by providing useful information regarding the capacity for the national veterinary services to contribute to core capacities outlined in the IHR (2005). While there are obvious areas of overlap between the JEE and PVS – for example zoonotic disease, food safety, antimicrobial resistance – it has been acknowledged that there are other areas that should also be considered together in order to achieve a more holistic understanding of the strengths and challenges in each system in a single country. This led to the OIE and WHO jointly issuing the *Handbook for the Assessment of Capacities at the Human–Animal Interface* (WHO, 2017) which brings these two sets of standards and assessments (WHO-JEE and OIE-PVS) together. The handbook explains the synergies and complementarities between the two tools, including information on how to align data from the PVS Evaluations in the JEE (WHO, 2017). Since 2016, there have been an increasing number of IHR-PVS National Bridging Workshops conducted under the WHO Strategic Partnership for International Health Regulations (2005) and Health Security (SPH) (e.g. see: https://extranet.who.int/sph/ihr-pvs-bridging-workshop (accessed 19 June 2020)), however, the longer-term impact of these remains to be seen. What is clear is that for One Health to survive, it is axiomatic that the veterinary profession remains a strong advocate of multidisciplinary approaches such as IHR-PVS to solving the complex challenges of global health, and is in a position to provide decisive leadership (Gibbs and Gibbs, 2013; Gibbs, 2014).

(ii) A need for more integrated 'systems' solutions rather than 'vertical' disease approaches

Concerns about the large investments that have been directed into vertical disease approaches for high-profile diseases such as HPAI, HIV/AIDS, tuberculosis and malaria have been raised in recent years (England, 2007; Leboeuf and Broughton, 2008; Molyneux, 2008; Maudlin *et al.*, 2009). Opponents argue that the tendency for global health projects and programmes to concentrate resources on single disease interventions can result in creating parallel systems outside of existing health systems, leading to criticism that donors in particular are ignoring the state of broader health systems in many countries (Marchal *et al.*, 2009; Mackey, 2016). One notable example describes how in 2005, the entire Ugandan Ministry of Health budget at the time (US$112 million) was swamped by US$167 million for HIV/AIDS funding from external donors (Marchal *et al.*, 2009).

Rhetoric surrounding integrated approaches to disease control and strengthening of the wider health systems in developing countries is often in stark contrast with the reality of the 'top down efforts to control particular diseases, one at a time' that continues despite the attempts of the SDGs to have a more integrated approach to global issues to 2030. Increased funding from a number of GHIs has also resulted in concern that pressure to demonstrate 'impact' has created a bias against a longer-term, more systemic approach to health care. This is compounded by the fact that the 'systems thinking' mechanism evolved relatively late in global health discourse; even now our understanding of how to improve health systems, and the available frameworks for doing so, remain limited (de Savigny and Adam, 2009). The result is that despite the huge increases in spending on global health, many global health systems do not have the processes in place to accurately measure their weaknesses and constraints, leaving policy makers unsure of what should actually be strengthened.

Promoting integrated approaches and a more participatory, problem-focused approach to disease control and health system management has afforded One Health further traction in recent years away from the pandemic to endemic narrative (Roth *et al*., 2003; Bechir *et al*., 2004; Schelling *et al*., 2005; Zinsstag *et al*., 2007; Godfroid *et al*., 2013; Leach and Scoones, 2013; Okello *et al*., 2014; Vandersmissen and Welburn, 2014; Mindekem *et al*., 2017). The realization that packaged, integrated solutions to human and animal health are vital to avoid overburdening district health units has led to several projects promoting integrated interventions and effective approaches to coexisting health issues, as opposed to 'stand alone interventions' (de Savigny and Adam, 2009). There is greater recognition that 'packaged' interventions simultaneously addressing a variety of health conditions for both humans and animals may reduce the risk of disease emergence and re-emergence if delivered via a sustainable livelihoods approach. For example, the growing evidence for the advantages of joint human–animal health systems in the diagnosis, prevention and control of zoonotic neglected tropical diseases (zNTDs) has led to an overarching recommendation to 'work towards the concept of One Health' to address diseases such as anthrax, bovine tuberculosis, brucellosis, cysticercosis, cystic echinococcosis, leishmaniasis, rabies and zoonotic trypanosomiasis (WHO, FAO, DFID and OIE, 2006; Maudlin *et al*., 2009; Gibbs, 2014). Other examples include the joint human and animal vaccine services for pastoralists in Chad, which demonstrated some of the earliest evidence of One Health in the 21st century; the focus on the district health offices remained central to the intervention (Bechir *et al*., 2004; Schelling *et al*., 2005; Häsler *et al*., Chapter 10, this volume). More recently in Lao People's Democratic Republic, an integrated intervention targeting soil-transmitted helminths, *Taenia solium* taeniasis and classical swine fever clearly demonstrated the added value of an integrated approach to the control of these diseases as a group (Ash *et al*., 2017; Okello *et al*., 2018).

(iii) Expand and strengthen One Health platforms

The threat of emerging pandemics has been a major driver for the proliferation of One Health projects and platforms that attempt to link animal, human and ecosystem health at both national and transnational levels, for example the Asia Pacific Strategy for Emerging Diseases (APSED) (Association of Southeast Asian Nations, 2010; UNSIC and World Bank, 2010; European Commission, 2011a,b; Hall and Ba Le, 2015). Another example is the Global Health Security Agenda (available at: https://ghsagenda.org/ (accessed 19 June 2020)), launched in February 2014 in response to the global threat posed by infectious diseases in an increasingly globalized and interconnected world.

The challenge remains across all regions of the world to support, build upon and broaden existing One Health platforms that were established for detection of emerging threats. Long-term institutional approaches to zoonoses management that sustainably strengthen the regional and national institutional base for One Health will require a rigorous assessment of governance structures, policy processes and actor networks, to better understand and inform decision makers on ways to optimize existing structures that promote One Health. Engaging key subnational actors has been shown to build understanding and shared learning between community members, local organizations and public services. Moreover, interventions that translate gender, knowledge, cultural practices and risk perception into disease control programmes, particularly those deemed 'community-led', are invaluable to improve acceptance and understanding (European Commission, 2008; Scoones, 2010).

In Asia and Africa, several One Health surveillance networks and partnerships have been in operation for some time: for example Uganda's Co-ordinating Office for the Control of Trypanosomiasis (COCTU) was formed by a parliamentary Act in 1992. This permanently funded interministerial platform coordinates policy for all stakeholders involved in tsetse and trypanosomiasis control in Uganda. While sleeping sickness is normally endemic, it can rapidly become an epidemic due to a range of human, animal and ecological factors. It is perhaps not surprising that lessons learned from over 100 years of human and animal disease control resulted in a One Health platform for disease management and risk mitigation for this particular disease (Welburn and Coleman, Chapter 21, this volume). The Asia Pacific region also has several national level platforms that have become key for building surveillance capacity and supporting implementation of the IHR and frameworks. Platforms such as the APSED complement regional organizations such as the Association of South East Asian Nations (ASEAN) and other biosecurity and bilateral trade agreements that underpin the bi-regional strategies of WHO South and East Asia Regional Office, WHO Western Pacific Regional Office, the FAO Regional Office for Asia-Pacific and OIE regional representation in Asia. At the district level, in some countries, participatory One Health platforms further build local leadership and ownership, and together enable a transdisciplinary culture to tackle health and ecosystem challenges.

There are also a number of additional academic networks in both Africa and Asia that aim to bring various stakeholders together to adopt and implement One Health approaches. For example the One Health Regional Network for the Horn of Africa (available at: http://www.zoonotic-diseases.org/what-we-do/flagship-projects/one-health-research-network-for-the-horn-of-africa-horn/ (accessed 19 June 2020)), and the Southeast Asia One Health University Network (available at: https://www.seaohun.org/ (accessed 19 June 2020)) and its various branches in countries including Malaysia, Thailand and Indonesia. Notwithstanding the significant political will and financial commitment required, building on established national and regional platforms originally developed for emerging infectious diseases can facilitate a One Health culture, strengthening existing ties between key stakeholders from the environmental, private and local community sectors (Vandersmissen and Welburn, 2014).

Maintaining and Building One Health Momentum – an Increased Need to Demonstrate the Added Value of One Health

Universally it is accepted that One Health expertise is required to tackle the human, animal and environmental challenges of the 21st century. The requirement to identify, control and manage human and animal diseases in complex ecosystems (Zinsstag *et al*., 2007; Welburn, 2011; Okello *et al*., 2014; Bunch and Waltner-Toews, Chapter 4, this volume), while having the added potential to contribute to food security (Nabarro and Wannous, 2014; Gordon *et al*., Chapter 25, this volume), is undeniable. However, while prevention of disease outbreaks is economically preferable to addressing a global pandemic, preventative measures require long-term financial commitments, which are difficult to justify if the total health impact is not calculated in national, regional or even global terms. Validated evidence demonstrating the added value of One Health in socio-economic terms is therefore a key component of the sustainability of the approach (Zinsstag *et al*., Chapter 31, this volume). In this way, estimations of *total societal burden* of, for example, zoonotic disease and antimicrobial resistance, can provide compelling evidence for investment in One Health (Narrod *et al*., 2012; Centre for Global Development and Social Finance, 2013; Okello *et al*., 2018).

Determination of the combined human, animal and environmental costs of disease to both the public and private sectors should therefore be prioritized by One Health practitioners, incorporating indirect impacts on food security of smallholder farmers with the economic effect of disease on livestock productivity and health. Operationalizing One Health in this way requires an appreciation and validation of the multidisciplinary linkages between human and animal health, ecosystems, livelihoods and policy processes, demanding support and consultation from all sectors or industries with a stake in health governance (Public Health Agency of Canada, 2009; CDC, 2010; USAID, United Nations System and World Food Programme, 2011; FAO, OIE and WHO, 2012). However, while significant investments into One Health approaches have demonstrated success in some regions of the world (e.g. Vigilato *et al*., 2013), evidence of the business case for One Health, and a fundamental understanding of the drivers, policies and systems of ‘what makes One Health work’ is still largely lacking. Importantly, there is an urgent need to better understand how the various approaches to health system strengthening have differed between the human and animal health sectors in recent decades – particularly in terms of the stark differences in levels of public investment – as this influences the extent to which mechanisms such as the IHR-PVS National Bridging Workshops will be effective. Standard characteristics that receive attention in the context of human health systems strengthening (e.g. labour markets, the impacts of alternative financing mechanisms and the nature and consequences of public–private partnerships) still require stronger evidence-based understanding in veterinary markets (McPake *et al.*, 2019). Additionally, many research programmes and projects lack a true ‘systems perspective’ incorporating environmental, socio-cultural and socio-political research investigations, hindering our progress towards cross-sectoral, holistic solutions to the ‘wicked problems’ of the 21st century even more. The processes with government and research institutions, in addition to animal and human health systems, will therefore also require strengthening if a One Health approach is to be realized.

Conclusion

With the right drivers, it has been possible to mobilize considerable political and financial support to achieve national, sub-regional and regional integrated approaches for the control of emerging or re-emerging zoonotic disease. The rapid evolution from the ‘simple’ response to H5N1 towards an emergence of a longer-term One Health movement has been unprecedented and timely in terms of global public health (Buzan *et al.*, 1998; European Union, 2010; Scoones, 2010).

Addressing new and recurring global health challenges requires a long-term, strategic approach to GHG. Management of the disease risks arising from interactions between animals, humans and the environment, demands integrated action from both human and animal health sectors, and support from other sectors or industries with a stake in health governance. The capacity for detection of emerging zoonoses and control of existing disease can be further increased with committed advocacy strategies, both at the higher policy levels and via engagement with affected communities to improve local disease surveillance networks. Institutional and private support for One Health is growing; a series of high-profile meetings initiated and supported by the EU, FAO, WHO and OIE, among others, has helped to foster political consensus and increase advocacy within the international community, highlighting the intersectoral action required for the ‘new’ approach to health.

The overwhelming message arising from this analysis of the multitude of actors, networks and policy alliances that govern global health today is the requirement for *balance*: to balance the needs of individuals with that of populations, of donors with their beneficiaries, of agenda setting from powerful GHIs with the traditional technical and research actors with the ability to adequately address systemic issues in health service delivery. It is within this complex maze of interactions that One Health could potentially play a role of ‘overseer’. Through exerting a non-biased authority over cooperation and collaboration between differing global health actors, One Health could help ensure the underlying philosophies of a holistic approach to health and nutrition – incorporating transdisciplinarity (Berger-González *et al.*, Chapter 6, this volume) and a *whole of systems* approach.

In conclusion, innovative solutions towards GHG will need to be found in order to overcome the challenges of global One Health coordination – given the wide variety of actors and agendas that now hold a stake. While One Health offers a rational choice where cumulative effects of disease on food, nutrition and livelihood security are considered, rolling out the approach requires a fundamental change in institutional operations, accompanied by long-term financial solutions, for which demonstrating the added value of One Health from a policy perspective will be key.

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31 Measuring Added Value from Integrated Methods: Towards a Game Theory of One Health

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Introduction

We have proposed a working definition of One Health as any added value in terms of health of humans and animals, financial savings or environmental services achievable by the cooperation of human and veterinary medicine when compared with the two medicines working alone (Zinsstag *et al*., Chapter 2, this volume). Cooperation between different disciplines should lead to an added value or synergistic effect. Otherwise such cooperation can be hardly justified, especially if it requires investment in time, financial resources and intellectual effort of connecting research and implementation methods. Many issues in human and veterinary medicine, like fundamental research, drug and surgery development, are indeed closely connected. Others are so highly specialized that they cannot and need not be interconnected. The use of animals as sentinels for human risk, like the use of canaries in coal mines, does not, strictly speaking, represent an added value example because it serves essentially public health, but Rabinowitz *et al*. emphasize considerations of sharing risk between humans and animals as a joint perspective on risk (Rabinowitz *et al*., 2006, 2008). The modern concept of One Health aims to identify areas in both medicines and their related sciences such as public health, which have the potential to generate further added value.

In Fig. 31.1, we list some areas where both medicines already collaborate closely or appropriately concentrate on their specialist field. Priority activities of One Health are presented as part of an intersecting set within a social-ecological system.

This chapter concentrates on the question of 'added value' as a constituent part of modern One Health conceptual thinking and will ground it within a wider theory of cooperation. Why this is needed has already been outlined (Zinsstag *et al*., Chapter 2, this volume) with the example of poor early communication between public and animal health authorities that contributed to the recent Q-fever outbreak in the Netherlands leading to thousands of avoidable human cases (Enserink, 2010). However, added value through fostered communication leading to earlier detection may be difficult to quantify in some instances, because alternative scenarios do not mean nothing would be done. For example, joint disease surveillance can be described qualitatively resulting in a shortened decision pathway.

What does an 'added value' of a closer cooperation of human and animal health and related disciplines really mean, and how can it be measured?

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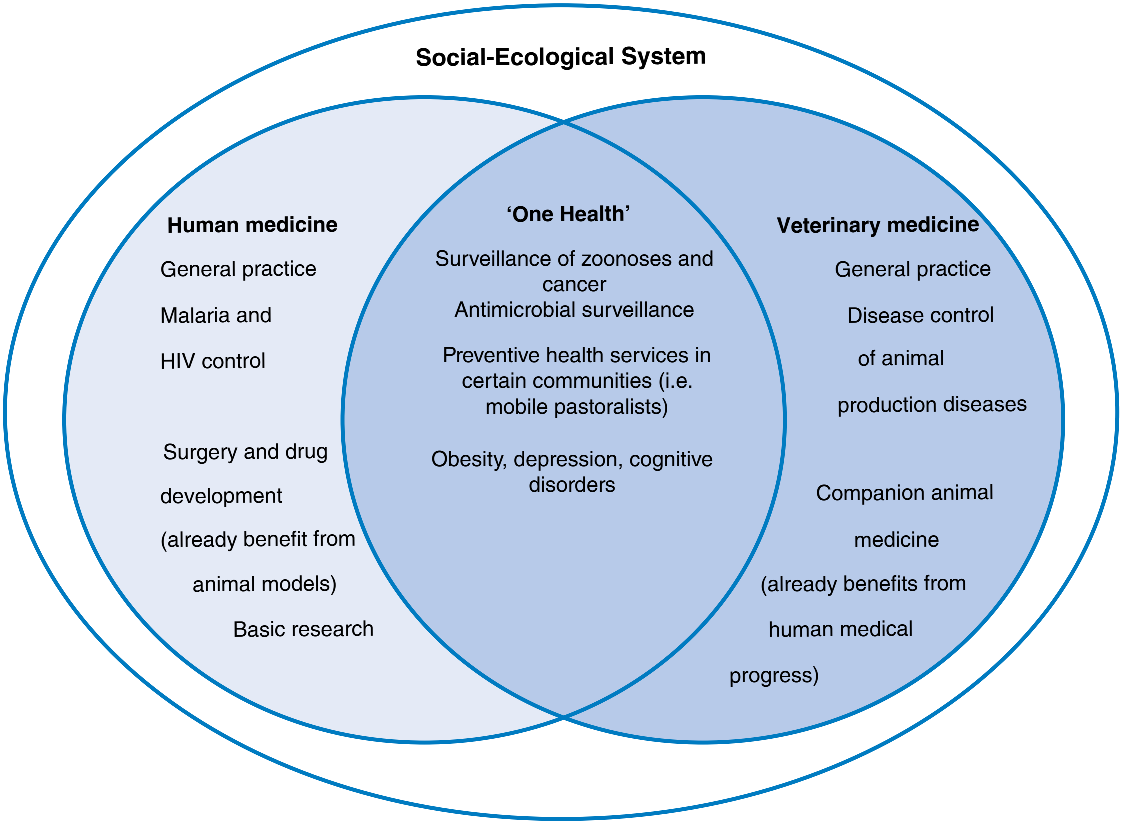

Fig. 31.1. Examples of 'stand-alone' activities of human and veterinary medicine (those listed on the left of the left-hand circle and right of the right-hand circle, respectively) versus priority One Health activities (those listed in the intersection of the two circles) that would generate an added value through closer cooperation.

Depending on the type of added value, new methods are required to quantify or qualify the benefits of such a closer cooperation. Added value of closer cooperation may appear at different levels within a web of causation (Fig. 31.2). The most proximal added values are *saved human and animal lives*, *reduced human and animal suffering*, *financial savings* and *improved ecosystem services* (such as pasture management, reforestation and safe water). Such a web is open and can be extended further as new evidence becomes available. It can be that a suggested animal–human–environmental linkage is actually only of marginal importance, and an integrated approach therefore is not necessary. For example, although bovine tuberculosis is an important animal disease in Ethiopia, we found only very few human cases and consequently did not include a public health economic assessment of its cost, but stayed with a restricted cost estimate for the Ethiopian livestock production (Tschopp *et al*., 2012; Tschopp and Yahyaoui, Chapter 22, this volume).

Reduced Time to Detection of Disease

Cross-sectional animal–human disease frequency studies on brucellosis and Q-fever may identify the animal source of human disease more quickly (Schelling *et al*., 2003; Bonfoh *et al*., 2012). This requires methods that are able to relate animal and human disease frequency in space and time (Schelling and Hattendorf, Chapter 8, this volume). Another example is the recording of the number of dog-bite victims for every rabies-suspected dog diagnosed in a veterinary laboratory (Kayali *et al*., 2003). This approach should be connected with studies on dog-bite victims in health centres and hospitals to obtain a more complete view on the effective incidence of suspected dog bites and

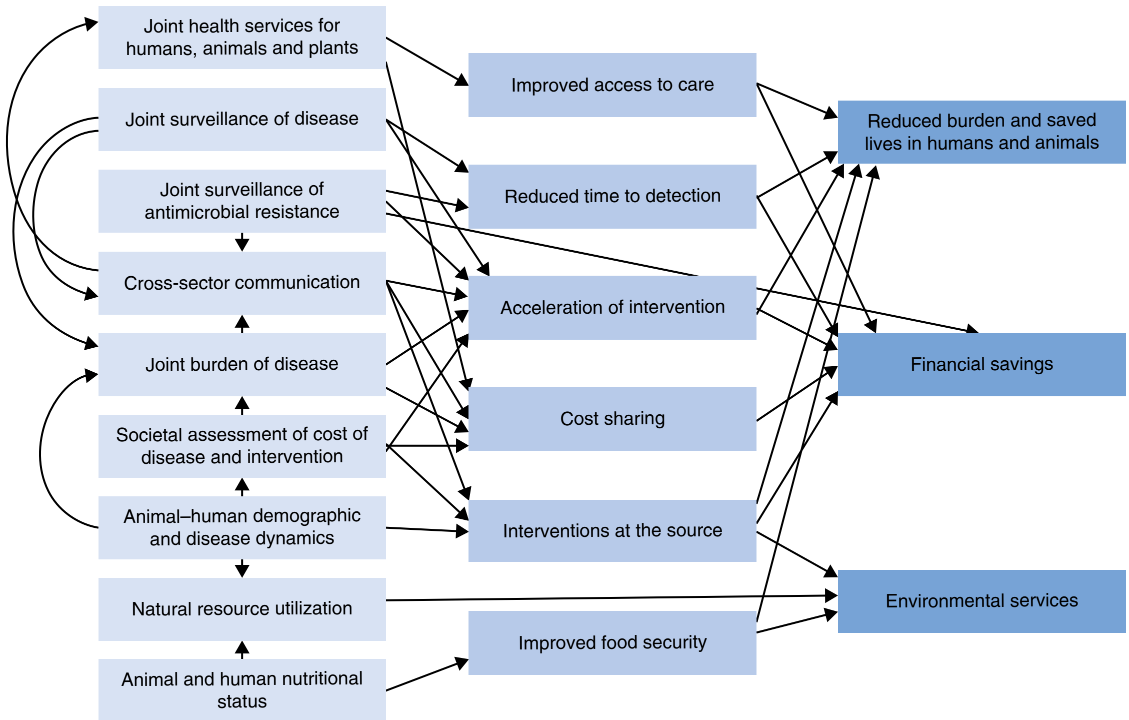

Fig. 31.2. Web of causation of distal and proximal added value of One Health.

human exposure (Cleaveland *et al*., 2002; Frey *et al*., 2013; Léchenne *et al*., Chapter 20, this volume). Ecological studies identify the linkage and importance of animal–human nutrition flows. In mobile pastoralist women in Chad we could show that human serum retinol levels depended on the milk retinol and beta-carotene content of their cattle (Zinsstag *et al*., 2002). Such studies can be extended to assessing the source of hygiene-related pathogens and contaminants like heavy metals (Forget and Lebel, 2001). At this point One Health is extended to ecosystem health, including ecosystem services (see below and Zinsstag *et al*., Chapter 2, this volume). The above examples result in *reduced time to detection and earlier intervention at the source*. A similar effect could be expected from interconnected surveillance of zoonoses in humans and animals, or of antimicrobial resistance. For example, the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) oversees the occurrence of antimicrobial resistance in humans, animals and the environment simultaneously (www.phac-aspc.gc.ca/cipars-picra/index-eng.php (accessed 19 June 2020)). This integrated surveillance involves not only the technical capacity, sharing of equipment and human resources, but most importantly *cross-sector communication* and decision pathways.

Joint Burden of Disease

Often diseases and health risks not only affect human lives but also animal lives. The assessment of the burden of disease in humans and animals is important for ethical, ecological and economic reasons. For example road traffic not only kills humans but also many more wild animals (Erritzoe *et al*., 2003).

Developing a single metric of disease burden of humans and animals is tempting. Indeed, the term 'zDALY' was coined to measure disease burden of humans and animals simultaneously (Torgerson *et al*., 2018). Monetary losses of animal diseases are thereby converted in time required to earn the income needed to replace the financial loss from the respective zoonotic disease and is then assigned as a disability adjusted life year (DALY) equivalent. However, by doing so, human life is indirectly assigned a monetary value, worse, it is dependent on the prevailing gross national income in a given country. Such a comparison is hardly justifiable, both for ethical and equity reasons. It would clearly mean that human life is worth less in a low-income country, when compared to high-income country. For these reasons, we clearly do not recommend extending the methods for the measurement of the burden of disease in humans (DALY) to animals but rather recommend the financial valuing of losses to animal production in a given context (Häsler *et al.*, Chapter 10, this volume). In turn, this does not consider the emotional value of companion animals that goes beyond a financial value of livestock. Similarly, the expression of the value of human life as Value of a Statistical Life (VSL) is controversial. The use of DALY has a broader acceptance in the health economic literature and in public health, because the former bears the risk of maximizing good health rather than minimizing ill-health burden (Shwiff *et al.*, 2013). For example, brucellosis transmission causes human suffering which can be expressed as loss in DALYs and a financial loss to livestock production (Roth *et al.*, 2003). In most cases the added value of a One Health approach is thus presented as an array of outputs composed of saved lives, financial savings and possibly qualitative gains. Assessing the *joint impact of disease in humans and animals* is thus an important added value for decision making.

Societal Cost of Disease and Sharing of Costs

Cross-sector economic studies address cost of disease to the sectors of public health, livestock production and other sectors such as markets and tourism. Interventions in one sector may result in benefits in the other sectors, thus providing a more comprehensive view of *the societal cost of disease and benefits of disease control*. This clearly adds value when compared to benefits of a single sector (Roth *et al.*, 2003; Zinsstag *et al.*, 2007; Häsler *et al.*, Chapter 10, this volume). Understanding the societal and ecological effects of a disease or risk provides the economic argument to negotiate the *sharing of intervention cost* between sectors, which reduces the cost to individual sectors, albeit not to society. In joint disease surveillance systems, further cost savings can be obtained from sharing of laboratory resources, expensive equipment and manpower. For example, the integrated, insect–wildlife–livestock–human West Nile virus surveillance system in Emilia Romagna, Italy saves money from preventing the use of virus-contaminated blood transfusion (Paternoster *et al.*, 2017). There is currently only a single laboratory in Chad capable of handling tuberculosis diagnosis, so it receives both human and livestock samples and saves financial and human resources from not running separate mycobacteria laboratories, one for public health and one for the veterinary services (Diguimbaye-Djaibe *et al.*, 2006; Diguimbaye *et al.*, 2006). The Canadian Science Centre in Winnipeg is a high-security laboratory for human and animal diseases under one roof. Savings on operations are estimated at 26% when compared with two fully separated laboratories (World Bank, 2012).

Interventions with Highest Leverage

Transmission of disease between animals and humans is often dynamic, requiring mathematical models to address non-linear processes (Chitnis *et al.*, Chapter 12, this volume). Such models allow simulating interventions in different sectors and together with economic analyses. In this way *interventions with the highest leverage, profitability and best cost-effectiveness* can be identified between all involved sectors. For example, a dog–human model of rabies transmission in an African city clearly showed that dog mass vaccination became more profitable and cost-effective after 6 years, when compared with human post-exposure prophylaxis alone. These results could not be obtained from separate studies in dogs and humans (Zinsstag *et al.*, 2009, 2017; Mindekem *et al.*, 2017). The best intervention for a zoonosis may be outside the health sectors. For example, neurocysticercosis in people can be effectively controlled by reducing open defecation in people and improved environmental sanitation.

Access to Care

Lack of access to health care for human and animals is one of the main reasons for the poor community effectiveness of health interventions (Obrist *et al.*, 2007). A better understanding of the factors determining access to health care and subsequent implementation may have an even higher leverage on the improvement of health status than a new drug or vaccine (Zinsstag *et al.*, 2011b). One such example emanated from a joint study of the vaccination status in humans and animals among mobile pastoralists in Chad. Livestock were vaccinated during compulsory veterinary campaigns, but no child was vaccinated. Negotiations with the Chadian health and livestock authorities led to joint preventive health services to humans and animals. This led to *improved access to care* for communities who were previously not served (Schelling *et al.*, 2007; Danielsen and Schelling, Chapter 14, this volume). In many developing but also industrialized countries, there is a permanent human resource crisis in the health and veterinary sectors. Service provision to humans, animals and plants is an open field for innovation (Danielsen and Schelling, Chapter 14, this volume). Scarce resources for transport are another critical aspect which may lead to new forms of cost sharing and cross-sector communication.

Food Security

Despite all the technical progress in food production, food security remains a painful shortfall across decades of international development cooperation. Its causes are a complex interplay of social, economic and ecological factors to which a One Health approach can contribute. Animal-source food (e.g. milk) and livestock production directly affect populations like mobile pastoralists (Bechir, 2010; Bechir *et al.*, 2011, 2012) but also a large part of the estimated 800 million small-scale farmers for which their livelihoods depend essentially or partially from livestock production (Gordon *et al.*, Chapter 25, this volume). Cross-sector studies of human and animal food security may lead to improved emergency planning for destocking and restocking of livestock in pastoralist production systems saving human lives but also reducing animal suffering. For example, during the drought period in 2006 in the Sahelian countries, early destocking and conservation of animal-source food on the spot could have saved substantial resources and human lives (Fig. 31.3).

Ecosystem Services

Addressing health issues at the human–animal interface depends on ecosystem services, such as clean water and adequate pasture for grazing. Work on brucellosis in Mongolia involving livestock demographic simulation revealed dramatic effects of political change and climate variability. The end of the socialist period led to a rapid increase of livestock populations, especially goats, because of the high market value of cashmere. At the same time, consecutive snow storm catastrophes (Dzud) killed tens of millions of animals. Overall though, the Mongolian livestock population increased to a level causing substantial degradation of pasture (Shabb *et al.*, 2013). Future Mongolian livestock development policy should consider stabilizing the livestock population size to maintain pasture availability. Future livestock production will depend on mitigation of pasture degradation. Animal disease control and elimination (e.g. foot and mouth disease) plays an important role for future livestock and meat export to reduce stocking density. This example shows how health and ecosystem services are intimately connected. This field of research is specifically addressed by 'ecosystem approaches to health' in which One Health is embedded (Charron, 2012; Zinsstag, 2012). Sustained or restored environmental services can be an important added value but their assessment requires advanced study design capable of measuring a causal relationship between health in humans and animals and ecosystem services. Future systemic study designs investigating human and animal health will quantify causal linkages to social-ecological systems resulting in an array of additional added values (Ostrom, 2007; Zinsstag *et al.*, 2011a).

Preliminary Conclusion

In this chapter we concentrate on examples of added value for which we have empirical evidence. Additional added value can be expected from numerous other aspects and types of collaboration between human and animal health. Joining of cancer registries for dogs and humans could possibly lead to an accelerated detection of environmental cancer risks. Living with dogs may reduce obesity and depression (Turner and Hediger, Chapter 23, this volume). Cognitive capacity may be improved from regular contact with dogs (Hediger and Beetz, Chapter 26, this volume). Joint human and animal health services could also be linked with plant health and improve access to plant health services (Danielsen and Schelling, Chapter 14, this volume). Joint contingency plans for epidemic diseases can improve management of outbreaks and decrease human and animal morbidity and deaths. In some

Fig. 31.3. Livelihood and food security of mobile pastoralists depend highly on their livestock and climatic conditions. Photo courtesy of J. Zinsstag.

cases of elimination programmes for zoonotic diseases, joint efforts are essential for success, as shown for rabies (Léchenne *et al*., Chapter 19, this volume). Insect repellents can decrease livestock infection with blood parasites and human malaria (Welburn and Coleman, Chapter 21, this volume). Healthy animals and humans are a prerequisite for sustainable wildlife conservation (White *et al*., Chapter 3, this volume). As a preliminary conclusion, the presented examples support the understanding of One Health as a measurable qualitative or quantitative added value of closer cooperation between human and animal health and other related disciplines and approaches.

Future outlook towards a game theory of One Health

Game theory plays an important role in evolutionary biology, showing that cooperation is a decisive organizing principle in life and specifically in human society (Nowak, 2006) and natural resources management (Ostrom, 2015). While several game theoretical principles are applicable in evolutionary theory, game theory has only been applied in a limited way to public health. The application of game theory in public health is most relevant when the actions of individuals or groups affect the health of others (Malhotra, 2012). Game theory applied to public health in hypothetical scenarios, using the prisoners dilemma and the Nash equilibrium, shows that community service provision results in financial benefits from the cooperation of public health providers (Westhoff *et al*., 2012). It further shows the need for communication between academic specialist and non-academic actors to provide the best services to communities and that cooperation is most beneficial for quasi-public goods in public health. Some caution applies to those statements because they were made on the grounds of hypothetical scenarios, without empirical experience of cooperation and with only two actors considered (Westhoff *et al*., 2012).

Game theory has been applied to social distancing in control of an epidemic (Reluga, 2010), sustaining effective coalitions between public and private health-care facilities (Ford *et al.*, 2004), medical ethics (Riggs, 2004), organ donation (O'Brien, 1988), bioterrorism (Hamilton and McCain, 2009), medical-resource development (Roth, 1984) and improving acceptability of primary health care (Tarrant *et al.*, 2010). Reeve-Johnson models veterinary health-care delivery using game theory (Reeve-Johnson, 2017).

Extending our perspective beyond public health to include animals and the environment, Elinor Ostrom showed how cooperation or collective action leads to sustained environmental services in smaller communities. Her first example analysed the collective action of the Törbel community (Wallis, Switzerland) who used their high alpine pastures in a sustainable way for centuries by only letting a strictly limited number of cattle graze them (carrying capacity). Ostrom criticizes the blanket metaphor of the 'tragedy of the commons' (Hardin, 1968), which assumes that common property is destroyed by the self-interests of individual actors (Ostrom, 2015). These examples show an array of qualitatively different benefits from closer cooperation and collective action, similar to the earlier presented section on joint burden of diseases.

In 2008, one of us (JZ) had a conversation with Elinor Ostrom, asking her if she ever considered health as an outcome of a social-ecological system (Ostrom, 2007). She answered that she never thought about that. The plan to work together unfortunately did not materialize but motivated us to propose the concept of 'health in social-ecological systems' (HSES) (Zinsstag, 2012; Zinsstag *et al.*, Chapter 2, this volume). Health of humans and animals is multifaceted. It has a purely private dimension and is probably the highest private asset in a person's life. Our own health is therefore our highest private good. But health also clearly has an important public and common dimension. By being infected by another person, or by infecting another person with a preventable (or non-preventable) disease, health becomes eminently public and global.[1] We can consider freedom of disease in its non-rivalrous (where consumption of a good by one person does not reduce the amount available for others) and non-excludable quality (Quilligan, 2012) as a common good in Ostrom's understanding (Ostrom, 2015).

By analogy, unhindered spread of disease, leading to outbreaks, or endemic stable transmission of disease can be considered as a 'tragedy of the commons', as described by Hardin (1968). For example, ongoing transmission of rabies in many West and Central African countries is indeed tragic, causing the deaths of tens of thousands of people, mostly children, every year (Hampson *et al.*, 2015). In contrast, if all people exposed to rabies-suspected animals could be protected with post-exposure prophylaxis (PEP), human deaths could be avoided, and if successful dog mass vaccination campaigns at sufficient coverage were done, rabies could even be eliminated (Zinsstag *et al.*, 2017), reducing its cumulative cost to the lowest figure (Mindekem *et al.*, 2017). Such a high level of cooperation across the levels of social organization, from household to national governments, which is needed to eliminate dog-mediated rabies requires a transdisciplinary participatory process between all actors of civil society, authorities and academic actors (Berger-González *et al.*, Chapter 6; Léchenne *et al.*, Chapter 19; this volume).

We further incorporate our initial thinking of One Health as an added value of a closer cooperation between human and animal health into the broader game theory of cooperation at the level of evolution, economics and natural resource management. We consider health of humans and animals, and metaphorically of the ecosystem,[2] as a basic social good (Okello *et al.*, Chapter 30, this volume), in the vocabulary of Rawls (1971). However, the premises of game theory must be carefully assessed for their use at the individual (individual health) level and as collective action for public health (Roemer, 2019). Cooperation for collective One Health action, using transdisciplinary participatory processes (Berger-González *et al.*, Chapter 6, this volume) at different levels from individuals, households, communities, provinces, countries and the international level becomes a central feature of the One Health approach. The different scales of social layers match well with the multilayered social resilience concept for mitigation research (Obrist *et al.*, 2010). Future work will develop a One Health game theoretical framework by specifying utility functions between the different public and animal health actors at different levels (individual and different levels of collective action) as a theoretically well-grounded methodological approach to solving health problems in social-ecological systems.

One Health, including the health of animals as co-creatures (Genesis 2: 15),[3] and the 'health' of the environment and ecosystems by sustaining their services like clean air, clean water and safe food, is the foundation of our health and well-being and opens up a post-humanist perspective, no longer putting only humans in the centre of attention. Such a broader co-creational perspective has considerable potential to change natural resource management, social science and humanities approaches.

Notes

[1] At the time of writing (January 2020), we witnessed the rapid spread of a new coronavirus (COVID-19) from Wuhan, China into the world.
[2] The metaphor of health can be applied to ecosystems which provide their services sustainably.
[3] Genesis 2: 15. And the Lord God took the man, and put him into the garden of Eden to dress it and to keep it (available at: https://www.kingjamesbibleonline.org/Genesis-Chapter-2/ (accessed 5 April 2020).

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32 Summary and Outlook: One Health in Practice

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> 'All science is nothing more than the refinement of everyday thinking.'
>
> (A. Einstein, 1936)

Confronted with the fascinating wealth of knowledge, evidence and potential directions to follow to make One Health a reality, one might feel overwhelmed or even partly lost. One Health thinking results in unintended consequences. This last chapter aims to provide a comprehensive overview of what One Health entails in practice: from its roots to the current positioning in the global health, and also planetary health scene, by building on historical elements and providing key theoretical, methodological and practical issues of One Health. Summarizing through a comparative synthesis, we aim to:

- reveal the essentials of One Health as they evolved;
- identify where substantial improvements can still be made in human and animal health;
- provide deeper considerations of the human–animal relationship and the exposure to complex problems that extend beyond current One Health thinking;
- work out One Health leadership and policy implications towards leveraging integrated approaches to health in development practice; and
- provide a research agenda for One Health and beyond.

A comprehensive view from theory to practice stimulates us to rethink our paradigms of science from a post-humanist perspective, which may influence the current anthropocentrism in the humanities and social sciences, but also currently fragmented natural sciences, which are not congruent with contemporary complex problem solving needs like climate change, ecosystems preservation, population dynamics and antimicrobial resistance.

Historical, Theoretical and Normative Issues of One Health

Over time, the interaction of human and animal health has been a strong mix of a history of ideas and a history of practices, meandering between very close and distant interactions between human and animal health across the centuries. It profited from a sequence of individuals who were strongly engaged in integrative thinking but also from general societal tendencies. The first chapter of the book (Bresalier *et al.*, Chapter 1, this volume) focused on a Western Euro–American perspective but the authors were well aware of a similar dynamic of human and animal health in other parts of the world, notably in China. Towards the end of the 19th century, modern science led to an increasing specialization and fragmentation, which particularly entailed concentration on smaller and smaller aspects of disease biology, separating human and animal health more and more. In the second half of the 20th century, Calvin Schwabe coined the term 'one medicine', inspired by the integrated way of life of humans and animals among Dinka pastoralists (Schwabe, 1984; Schwabe and Kuojok, 1981). One medicine evolved to One Health, further considering its importance at the level of populations and its potential to strengthen health systems (Zinsstag *et al.*, 2005). One Health (Woods *et al.*, 2018) emerged as a conceptual term, later fuelled by pandemic threats,

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ecosystems health and conservation issues. At the same time, One Health is part of a stream of integrative thinking that limits itself not only to humans and animals but extending to broader social-ecological systems thinking. One Health appears likely to be an intermediary movement towards a more integrative science, complementary to conventional reductionist approaches (Bresalier *et al.*, Chapter 1, this volume; Bunch and Waltner-Toews, Chapter 4, this volume).

Thinking about a closer cooperation of human and animal health has deeper consequences. The interaction of humans and animals is a permanent issue of reflection because of our biological closeness. Very strikingly and often overlooked, One Health also challenges current law when we scrutinize legal aspects of the human–animal relationship. Currently several countries have assigned a new status to animals (Wettlaufer *et al.*, Chapter 11, this volume). In the same chapter, progress for animal welfare in international law is detailed, and the ongoing debate regarding the moral status of animals is addressed from a legal perspective. One Health contributes to and even guides this debate with ramifications into the struggle for human rights, which is, for example, also often associated with cruelty to animals.

While the animal–human relationship at a conceptual and philosophical level is addressed in several chapters of this book, we concentrate here on the practical consequences of a closer interaction of humans and animals in health. At the concrete practical level, implementing a closer and coherent interaction between human and animal health within a given health, social and ecological system will undoubtedly lead to an incremental effect, a measurable added value (Zinsstag *et al.*, Chapter 31, this volume). The added value of One Health clearly reaches far beyond understanding and controlling zoonotic diseases, with important ramifications which impact, for example, the fields of mental health and social well-being (Hediger and Beetz, Chapter 26, this volume) as the experiences documented with animal-assisted therapy illustrate (Hediger *et al.*, 2019).

There is a strong ecological and conservation perspective of One Health when a broader ecosystem-health thinking is applied (White *et al.*, Chapter 3, this volume). The current One Health movement is positively stimulated by the wildlife conservation movements. Conservationists recognized at an early stage that sustained wildlife ecosystems depend on healthy people and healthy livestock around conservation areas. The so-called 'Manhattan principles' are an important road map for One Health action and at the same time reach beyond the interaction of human and animal health, creating a clear linkage of health and ecosystems. With the rapidly growing dynamic effects of climate change and the respective growing worldwide concern, One Health remains in the focus, because it creates the incremental benefits for the triad of the health and well-being of humans, animals and the environment (Zinsstag *et al.*, 2018; Stephen *et al.*, Chapter 17, this volume).

Animal–human interactions are also driven by human behaviour and attitudes towards animals – as companion animals, food producers, agricultural work animals and food sources. The meaning of animals is always determined by cultural and religious factors requiring a close interaction with and incorporation of cultural sciences and humanities. Social aspects like gender, age and poverty affect acceptability, affordability and accessibility to human and animal health services and clearly require broad scientific contributions, particularly from the social and cultural sciences and anthropology (Whittaker *et al.*, Chapter 7, this volume). One Health is a living example of transdisciplinary science and practice. The challenges faced in One Health are multidisciplinary in nature and can only be tackled through interdisciplinary approaches, and the results in research and practice are always transdisciplinary.

One Health: Methods and Approaches

One Health advocacy and the translation of One Health strategies into public and global health practice requires sound evidence for its incremental value in terms of saved human and animal lives or saved resources. In addition, quantitative evidence must be complemented by qualitative evidence such as emotional stability resulting from the human–animal bond. Capturing these effects always calls for a mixed-methods approach at different levels of the animal–human interface. For example, the social animal–human interaction includes behaviour but also psycho-biological issues, such as when touching or stroking an animal (Hediger and Beetz, Chapter 26, this volume). Animal–human epidemiological studies assess human and animal health simultaneously. The design of such studies is challenging with regards to the different manners and dynamics of aggregation (clustering) of animal and human populations (Schelling and Hattendorf, Chapter 8, this volume). Being able to capture these complex human and animal population dynamics allow for simulating transmission of diseases between animals and humans which in turn leads to the quantification of the zoonotic potential of infectious diseases (see below and Chitnis *et al*., Chapter 12, this volume). The current decade of rapid worldwide digitalization offers new methodological avenues. For example, novel methods for human and animal health and demographic surveillance based on mobile communication, and machine learning offer new and transformational potential for syndrome-based disease surveillance and interventions at high accuracy and sensitivity (Aenishaenslin *et al*., Chapter 9, this volume). Similarly, modern cross-sector economic approaches show cost savings and the potential of cost sharing across the sectors of public health and the society as a whole (Häsler *et al*., Chapter 10, this volume).

Practical Examples of the Added Value of One Health

Section 3, Chapters 16 through to Chapter 27, provides practical examples from the use of One Health methods in the fields of zoonoses control of brucellosis, bovine tuberculosis, rabies and trypanosomiasis but also in non-communicable diseases, integrated health services, disaster and resilience, wildlife conservation, plant health, food security and nutrition and spiritual health. The practical examples impressively demonstrate the added value of One Health and aim at a truly holistic view of health (see also Zinsstag *et al*., Chapter 31). A One Health approach provides evidence for outcomes that cannot be achieved when physicians and veterinarians, and health-related disciplines, work in isolation. However, reviewing two decades of work in the domain of One Health unfortunately reveals that true mutual learning across disciplines, systems and functions still remains rare. Many studies claim a One Health approach, yet restrict themselves to demonstrating only facets of the interactions between human and animal health without coherent analysis and documentation of the incremental benefits from working together.

Studying human and animal health simultaneously reduces time to detection of the source of a zoonotic disease in an animal reservoir. Moreover, simultaneous investigations allow quantifying the relative transmission potential of zoonotic transmission between animals and humans and vice versa. One Health studies assess the effect of interventions in animals on human health and thus characterize the animal–human interface quantitatively and qualitatively. They further shift the perspective of economic analysis from public health to other sectors like agriculture, private households, tourism and the society as a whole, which provides new perspective on financing models of health and social services in a given setting. As outlined earlier, broader societal and ecological considerations of wildlife conservation were at the origin of the current One Health movement. Institutional frameworks relating public health and livestock production were created well ahead of the current One Health movement, in the form of Veterinary Public Health (Steele, 1949; Steele *et al*., 1998). More recent examples are the pandemic threats of severe acute respiratory syndrome (SARS) and avian influenza at the beginning of the 21st century. Other examples showed how the provincial and national levels can trigger future innovation in the way governments organize the interaction between human and animal health at all levels (Welburn and Coleman, Chapter 21, this volume; Rinchen *et al*., Chapter 29; this volume). Another key example is the operationalization of joint human and animal health services (Danielsen and Schelling, Chapter 14, this volume). A more recently integrated surveillance and response systems is the example of West Nile virus in Northern Italy which demonstrated cost savings from combining surveillance of mosquitoes, wild birds, horses and humans simultaneously (Paternoster *et al*., 2017a,b).

Reduced Time to Detection of the Source of Infection

Delayed detection and diagnostic errors of zoonotic diseases are among the most striking examples in favour of One Health. In Mauritania, presumptive cases of yellow fever in humans were subsequently diagnosed as Rift Valley fever after communication with the veterinary services. Similarly, public health authorities in the Netherlands complained about lack of communication from the veterinary services regarding a Q-fever outbreak in goats, which caused several thousand human cases. In both situations, better communication between the veterinary and public health services would have significantly reduced the time to detection of the first human cases by several weeks or months, and many human cases could have been avoided (Zinsstag *et al*., Chapter 2, this volume). Simultaneous animal and human studies allow for identification of the animal host reservoir of human disease and vice versa. In this way, sheep were identified as the most likely reservoir for human brucellosis in Kyrgyzstan. In contrast, despite the presence of bovine brucellosis in cattle, only very few – much lower than expected – human cases could be identified in Togo (Schelling *et al*., Chapter 20, this volume). These striking examples lead us to conclude that in view of emerging and re-emerging diseases and the need for swift interventions, any public health system requires effective surveillance–response approaches across sectors and also that health management information systems require not only a One Health approach but also a shift from monitoring and evaluation to surveillance–response approaches (Tambo *et al*., 2014; Aenishaenslin *et al*., Chapter 9, this volume).

Quantifying the Relative Transmission Potential of Zoonoses

The examples included in Section 3(a) show that brucellosis is comparatively easily transmitted to humans, with the exception of in Togo, when compared to rabies or bovine tuberculosis. Among the *Brucella* spp. it seems that *Brucella melitensis* is more readily transmitted to humans than *Brucella abortus*. In Mongolia, the small ruminant-to-human transmission constant was 13 times lower than that between small ruminants (i.e. one infected small ruminant infected 13 other small ruminants before one person was also infected). Assuming that cattle were mostly infected with *B. abortus*, the cattle-to-human transmission constant was 165 times lower than between cattle transmission. Such findings are still very rarely documented and need to be further assessed (Chitnis *et al*., Chapter 12, this volume). As for rabies, each rabid dog exposes on average 2.3 humans but the dog–human transmission constant was 403 times lower than the between-dog transmission constant (Zinsstag *et al*., Chapter 31, this volume). The transmission through an animal bite certainly represents a unique pathway, which highly depends on the contact network and direct contact frequency between the reservoir host and humans (Léchenne *et al*., Chapter 19, this volume).

It has become increasingly evident that the zoonotic transmission potential of bovine tuberculosis due to *Mycobacterium bovis* is lower than expected. To our knowledge, no comparative transmission constants between cattle and from cattle to humans exist, but the proportion of human *M. bovis* infection is on average only 2.8% of all human tuberculosis cases. On the other hand, *Mycobacterium tuberculosis* has been found in cattle, goats and even camels, and there are documented cases that people with *M. bovis* have reinfected cattle, demonstrating two-way transmission of diseases between animals and humans (Tschopp and Yahyaoui, Chapter 22, this volume). In the same chapter, the importance of the wildlife–livestock interface is highlighted, with a call for more evidence to estimate the respective risk of *M. bovis* on communal pastures in the proximity of game parks. The first cattle–human *M. bovis* transmission model is also presented with the example of Morocco, inspiring reflection about strategies for elimination. From these observations, and based on similar One Health studies, a theory of interspecies transmission which is firmly based on real observations emerges and this stimulates new and more basic research questions on other zoonotic pathogens with varying reproductive numbers. The most important interdependent determinants are: (i) the relative animal and human host densities; (ii) the mode of transmission; (iii) the within- and between-host contact network; (iv) the virulence of the pathogen; and (v) the susceptibility of hosts.

Quantify the Effect of Interventions in Animals on Public Health

Livestock brucellosis vaccinations clearly reduce human brucellosis incidence, which cannot be shown by studying transmission in humans and livestock separately. Studying brucellosis control in humans and animals simultaneously, as well as in other affected sectors such as coping costs of households, shifts the perspective of an economic assessment from the public health sector into the broader societal context. A cross-sector economic analysis of brucellosis control by mass vaccination of livestock demonstrates that, from a societal point of view, brucellosis control becomes cost-beneficial whereas from a public health point of view alone it would not. These calculations do not yet include other consequences of brucellosis infection like loss to export markets. Brucellosis provides a prime example of a One Health approach, showing how interventions become cost-beneficial when viewed from a broader societal perspective (Häsler *et al*., Chapter 10, this volume). The cost–benefit for a country and the cost-effectiveness for public health are also clearly shown for zoonotic trypanosomiasis (Welburn and Coleman, Chapter 21, this volume). Trypanosomiasis control in Ugandan cattle resulted in a reduction of the prevalence of the sleeping sickness parasite in cattle by close to 70% and human cases of human African trypanosomiasis (HAT) by 90%, with a 75% reduction of all trypanosomes in cattle (human and cattle pathogens). Furthermore, treating a reasonable proportion of cattle with insecticides can lead to elimination of the disease. It follows that if a sustainable spraying intervention at cattle markets is developed, tsetse-transmitted zoonotic trypanosomiasis will cease to be a problem, and sleeping sickness due to *Trypanosoma brucei rhodesiense* will be eliminated (Welburn and Coleman, Chapter 21, this volume).

A similar case can be demonstrated for rabies (Léchenne *et al*., Chapter 19, this volume). The current vaccine investment strategy of Gavi, the Vaccine Alliance to include rabies post-exposure prophylaxis (PEP) in its vaccine portfolio is likely to contribute strongly to the 'zero human rabies by 2030' aim, but it will not interrupt rabies transmission. Long-standing dog rabies mass vaccination strategies can eliminate rabies and are more cost-effective than human PEP beyond a time horizon of 10 years.

Using transdisciplinary, participatory approaches for engagement between public and animal health, communities and authorities is a critically important method for One Health. Berger- González *et al*. (Chapter 6, this volume) showcase examples from Guatemala and Ethiopia, which used a transdisciplinary approach from the early planning stages of the projects onwards. This allowed extension of transdisciplinary methods to intercultural and multilingual contexts, showing the important role of internal and external project communication for successful management of One Health projects.

One Health and Non-communicable Diseases

Although it is often overlooked, One Health has also a high potential for addressing non-communicable diseases. Turner and Hediger (Chapter 23, this volume) demonstrate that companion animals contribute significantly towards human health in a number of ways, like reducing obesity, depression and survival after ischaemic heart failure. Not only is public health affected, but also increasingly, the health of individually challenged persons through animal-assisted interventions, which has become, in the past decade, the focus of a number of international organizations and non-governmental organizations (NGOs). One Health is a main avenue to tackle the direct and underlying causes of food insecurity, malnutrition and poor health and maximize human, animal and environmental well-being. Knowledge about animal nutritional status becomes an essential part of planning effective, cost-efficient human food security interventions. In addition to economic and human health, benefits are derived from investing in animal health, while land use policies are also important. In fragile areas with insufficient pasture, overstocking and high grazing pressure, poor animal health results in decreased productivity and increased mortality, so animal health measures cannot be neglected. Such complex intersectoral linkages must be carefully considered for optimal resource utilization and sustainability (Gordon *et al*., Chapter 25, this volume), a major challenge still ahead of us.

Cost Savings from Joint Services and Sharing of Intervention Cost

Initially the most striking set of interventions addressing the cost-effectiveness of One Health interventions concerned vaccination services. One Health studies in many settings among mobile pastoralists and their livestock showed a relatively high proportion of vaccinated cattle, whereas the vaccination coverage of children and women was extremely low (Danielsen and Schelling, Chapter 14, this volume) reflecting that livestock was given priority over mother and child health. Subsequent joint animal and human vaccination campaigns not only increased compliance to vaccinations, but also universal access, and most importantly, saved 15% for the public health sector when compared with providing separate human and veterinary services (Häsler *et al*., Chapter 10, this volume). Furthermore, it indicates the entry points into how a broad health system can be strengthened to reach universal access in areas of pastoralist societies.

Similarly, Danielsen and Schelling (Chapter 14, this volume) show that plant clinics have a wider role to play in general agriculture and human health. Examples include diagnosis of pesticide poisoning and giving advice on safe pesticide use, as well as planting of nutritious crops. Advice on plant and animal health could be given at the same location. Plant clinics could also be run in parallel with maternity clinics. Many women are important producers and would benefit from advice on which crops would improve family and community nutrition. Such ideas require further validation and investigation on how they can be tailored to different places and contexts.

Finally, the case study of brucellosis control in Mongolia mentioned earlier shows that if intervention costs were allocated proportional to the monetary benefits, only 11% of the intervention costs would be debited against the public health sector. Including the non-monetary benefits to human health, measured in averted disability adjusted life years (DALYs), the cost per DALY averted amounts to US$19 (Häsler *et al.*, Chapter 10, this volume; Schelling *et al.*, Chapter 20; this volume).

One Health Institutional Set Ups, Leadership and Policy

Welburn and Coleman (Chapter 21, this volume) present the Coordinating Office for Control of Trypanosomiasis in Uganda (COCTU), which is the governmental body responsible for coordinating and monitoring sleeping sickness interventions in Uganda – a concrete example of a One Health platform that is working in practice. This permanently funded interministerial platform coordinates policy for all stakeholders involved in tsetse and trypanosomiasis control in Uganda. COCTU is an example of effective national ownership and shows Uganda's foresight and commitment to One Health, long before intersectoral zoonoses working groups became fashionable in the course of pandemic avian influenza preparedness actions. Despite ongoing financial challenges, the Ugandan ownership and high-level political endorsement of COCTU demonstrates how One Health success is likely to be more sustainable and appropriate for interventions when nationally owned.

One Health policy development shows that there is no magic formula for the success of a One Health approach, but success is achieved with good governance and a clear set of agreed-upon goals and objectives should be an integral component. Taking a more integrated approach, as well as engaging a One Health team, has ensured that the policies developed are acceptable to the public and to relevant industry stakeholders and are, therefore, more readily implemented. Although the application of the One Health concept to the development and delivery of science-based policy is not new in South-east Asia, there remain challenges with regard to engaging communities and stakeholders in the development of policy (Nguyen-Viet *et al.*, Chapter 13, this volume; Rinchen *et al.*, Chapter 29, this volume). National ownership and developing effective partnerships between scientists, communities, industry stakeholders and policy makers are key to increase awareness, successful policy acceptance and effective implementation in each of the settings studied so far (Berger-González *et al.*, Chapter 6, this volume). Consequently, a more global assessment about integrating health governance with national priorities, as described in Chapter 30 (Okello *et al.*, this volume) shows that 'One Health is a public good that cannot be owned and that should remain flexible, based on a broad pool of multiple expertise that cross disciplines and countries' (CDU and EU, 2011). The positioning of One Health within a public health system and within the global agenda becomes a key element for the continued effectiveness of One Health in any given social, political and ecological setting. One Health offers rational choices because cumulative effects of disease on food and economic security are considered. Effectively implementing One Health implies further changes in institutional operations and long-term adequate financial solutions. The added value of One Health in socio-economic terms has to be demonstrated for these solutions (Okello *et al.*, Chapter 30, this volume). One Health has gained a growing international dynamic and recognition, which we reflect here using examples from the Americas, selected African and South-east Asian countries and Switzerland. Many countries successfully test novel models of closer cooperation between ministries, NGOs, bi- and multilateral organizations and communities (Pelican *et al.*, Chapter 15, this volume; Oura *et al.*, Chapter 28, this volume; Rinchen *et al.*, Chapter 29, this volume; Okello *et al.*, Chapter 30; this volume). The comparative analysis reveals undoubtedly that transdisciplinary approaches engaging with all actors, are the key for practical problem solving (Berger-González *et al.*, Chapter 6, this volume). It remains that this learning about policy and governance processes is put in the regular planning and resource allocation cycles within the frame of comprehensive subnational health management.

This in turn also calls for further emphasis on education and capacity building as reflected in case studies where we see increasing numbers of One Health teaching programmes, practical and academic courses and shared faculties of medicine and veterinary medicine (Oura *et al*., Chapter 28, this volume). It is our hope that the present book also becomes a cornerstone for renewed efforts in training and capacity building of and within One Health.

Outlook and Some Consequences

We started our review by tracing the roots and evolution of One Health and by understanding how concepts and approaches were changed. We used a number of practical examples from different social, cultural, political and ecological settings to show that One Health has become a reality in our thrust to achieve sustainable development. Many challenges lie ahead of us to become truly effective at all levels. On the other hand, and returning to the start of our thinking, we realize to what extent developing, validating and applying One Health has brought us to a much broader reflection on the implication of science.

Analysing One Health as a subject of scientific inquiry and as a concept and strategy in public health leads to a deep understanding of the animal–human relationship within distinct social-ecological environments. We recognize an inextricable linkage and apply the metaphor of health additionally to non-living things like ecosystems which in turn triggers fundamental thinking about health. Houle, in the first edition of the current book, refers to the philosopher Spinoza with regards to the potential of life of all creatures (Houle with contributions by Tschanz Cooke, 2015). She develops a broader concept of health from the potentials of life trajectories. Health equally involves issues of the beginning and the end of life. Death can be attributed with a normative dimension of a ‘good death’ after a fulfilled life as opposed to ‘bad death’ resulting from premature death from illness, violence, poverty and social inequity. Fries and Tschanz Cooke (Chapter 27, this volume) present the spiritual dimension of health as an extension of physical and mental health and well-being, clearly emphasizing a transcendent dimension of health. Although the spiritual dimension of health plays only a very limited role in animals, it still is a critically important dimension to an integrated concept of health. Including health and well-being of animals in our thinking is an age-old issue when we consider, for example, the messianic prophecy of ‘animal peace’ in the Old Testament suspending the enmity between animals and humans and between animals and animals.

> The cow will feed with the bear, their young will lie down together, and the lion will eat straw like the ox. The infant will play near the cobra’s den, and the young child will put its hand into the viper’s nest.
>
> (Isaiah 11: 7–8)

Such fundamental rethinking may also stimulate reflections on a new science of health, as partially but clearly addressed by Bunch and Waltner-Toews (Chapter 4, this volume).

All complex problems may not be addressed through reducing them to smaller processes. It leads to fragmentation from which generalization becomes difficult. The consequence is that we must attempt to gain a broader perception of the linkages between human and animal populations, and the economic, ecological and social processes which are part of ecosystem approaches to health. This will allow for identification of critical points of leverage for disease control and elimination without harming the environment, possibly even restoring ecosystem services. One Health activities will need to consider the larger implications of choosing certain health-related outcomes such as disease control or food production over others such as local community autonomy and resilience, and equitable and sustainable distribution of both production and consumption. It is in the context of these larger questions that ecohealth and One Health and their theoretical foundations in complexity theory and philosophical extensions called ‘post normal science’ may ultimately demonstrate their real and practical value (Bunch and Waltner-Toews, Chapter 4, this volume).

One Health thinking as an integration of human and animal health and well-being has significant (unexpected at the outset) consequences on the philosophy of science. Three components are central:

First extending a purely anthropocentric perspective to what we can call a post-humanist perspective including the well-being of animals and the environment as a whole challenges contemporary paradigms in the humanities and the social sciences. Humans are no longer alone in the focus of attention but their perspective expands to the environment and animals as own entities requiring full consideration. An increasing number of animal philosophers argue from a radical non-speciesist perspective for vegetarian and vegan positions (Grimm and Wild, 2016). Efforts are made to foster worldwide animal protection, for example through the global animal law project (www.globalanimallaw.org (accessed 19 June 2020)).

Secondly, from an integrated perspective on health, freedom from diseases and illnesses can be seen as a common good in Elinor Ostrom's understanding of 'the commons' (Ostrom, 2015). In as much as common natural resources, freedom from disease belongs to common property. Consider rabies: it makes a big difference living in a rabies-free country like Switzerland when compared with, for example Mali or Chad, where the risk of being exposed to a rabid animal bite is real. Eliminating rabies in Mali or Chad is clearly of public interest and thus warrants public engagement as a cooperation between public and animal health professionals, communities and authorities at different levels analogous to the socially layered resilience concept by Obrist *et al.* (2010) as mentioned by Zinsstag *et al.* (Chapter 31, this volume). Freedom from rabies can be seen as the ultimate benefit from socially multilayered intersectoral cooperation, which is a case for game theoretical considerations as a single player of multiscale games. Considering health and environmental resources as a common good leads towards a generic and generalizable perspective of health of humans, animals and their surrounding environment. The ongoing coronavirus pandemic (COVID-19) could hardly be a better example for the urgent need for a better local and global cooperation across sectors.

Thirdly, One Health systemic thinking of health as an outcome of social-ecological systems (Zinsstag *et al.*, Chapter 2, this volume) with its participatory transdisciplinary approaches (Berger-González *et al.*, Chapter 6, this volume) provides a goal-oriented alternative to fragmented natural sciences, which are not congruent with contemporary complex problem solving like climate change, ecosystem preservation, population dynamics and antimicrobial resistance. Clearly, reductionist scientific approaches maintain their primordial importance in knowledge generation, but should be complemented by integrative ways of generating new, transformational knowledge for societal problem solving that cannot be achieved by a single discipline. The European Research Council (ERC) can be cited as an example. Its numerous panels are organized along a strictly disciplinary orientation. Highly innovative interdisciplinary basic research projects simply do not match such funding structures which, inevitably, promote disciplinary scientists.

One Health is part of global and national public health whose legal and institutional aspects have been well described (Wettlaufer *et al.*, Chapter 11, this volume; Okello *et al.*, Chapter 30, this volume). Global health emerged from the discussion of and on 'international health' and its relevance for the future at all levels.

Gobal health (Koplan *et al.*, 2009) and its recent extension to planetary health (Horton *et al.*, 2014) through the full integration of the ecosystem (Whitmee *et al.*, 2015) provides the common umbrella and framework together with its complex underlying global health initiatives by bi- and multilateral organizations, NGOs and charities. One Health can be found in many of the ongoing and planned approaches for mainly rural, but also urban settings. However, One Health so far has no coherent and well-defined profile, be it for research, capacity building or direct public/global health action. One Health does not and should not become an 'own' global health entity, but rather an essential prerequisite for a comprehensive, integrated approach to health and well-being. In fact, the original primary health-care concept of 1978, as well as the reiterated call for 'Primary Health Care – now more than ever' (WHO, 2008), entail One Health in their concept. However, the conceptual thinking was never translated into strategies tailored to the various epidemiological and socio-cultural and socio-ecological settings where One Health could make a real difference in health outcomes and strengthen health and societal development at large. This lack of conceptualization and integration of One Health can be well understood when we analyse how the initial primary health concept was – soon after the Alma Alta declaration – fragmented into a series of very vertically organized initiatives such as: (i) maternal and child health programmes; (ii) TB (tuberculosis) and leprosy programmes; and (iii) essential drug programmes. The initial systemic approach was lost and hence the chance to bring in One Health was missed or even lost. One Health is a highly systemic approach and thus was deeply contradictionary to all prevailing global health initiatives until the systemic approach got a new push through 'health systems thinking' (de Savigny *et al.*, 2004; de Savigny and Adam, 2009). In this context, it is remarkable that One Health is still either inappropriately or not at all considered within the various documents on how to achieve the Sustainable Development Goals (SDGs). We deeply hope that the contributions summarized in this book, together with the wealth of evidence from research and validation of approaches on One Health, will find their way to consolidation in the strategies to achieve the SDG-agenda and our global development practices, the way One Health becomes an integral part of the global and planetary health agenda, and reality of public health practice.

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One Health

2nd Edition

The Theory and Practice of Integrated Health Approaches

Edited by **Jakob Zinsstag**, **Esther Schelling**, **Lisa Crump**, **Maxine Whittaker**, **Marcel Tanner** and **Craig Stephen**

One Health, the concept of connecting veterinary and human health, has now expanded beyond infectious diseases and zoonoses to incorporate a wider suite of health issues and a broader scope of practice. Closer cooperation between human and animal health disciplines is proven to result in measurable lives saved, better health, faster detection of new disease, and financial savings. In this new edition, the expert author team illustrates the contribution of One Health collaborations to real-world issues such as sanitation, economics, food security and vaccination programmes.

Retaining its interdisciplinary focus which combines theory with practice, the book includes more non-infectious disease issues to mirror the changing field of One Health. It promotes an action-based, solutions-oriented approach through practical content on methodological tools, data gathering, monitoring techniques, study designs, and mathematical models. New to the second edition are:

- Revised case studies that draw out implications for practice;
- Coverage of issues such as climate change, the Sustainable Development Goals and global food security;
- Expanded methodology chapters to include skills relevant to emerging issues;
- Expanded methods sections incorporating leadership and perspectives needed for success.

Extending its global relevance through a wider author team, *One Health: The Theory and Practice of Integrated Health Approaches* combines research and practice in one broad-ranging volume. As the world faces increasing risks from zoonotic diseases, this edition could not be timelier in highlighting lessons for human and animal health professionals, students and policy and development decision makers.

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