# 30

# One Health: Interdependence of People, Other Species, and the Planet

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## CHAPTER OUTLINE



## I. UNPRECEDENTED CHALLENGES, HOLISTIC SOLUTIONS

Population growth and the globalization of economic networks have resulted in a rapidly changing, highly interconnected world. The global human population surpassed 7 billion inhabitants in 2011 and is expected to reach 9.3 billion by 2050 and 10 billion by 2100.[1] The resulting demands for living space, land, food, water, and energy have become an increasing challenge. Never before have global issues of environmental sustainability and the health of humans and animals been so closely interconnected. To broaden our thinking on the scope and magnitude of these shifting global trends, we introduce a number of anthropological, environmental, and economic issues that ultimately relate to human health (Figure 30-1).

These health and sustainability consequences of global change are economically, socially, medically, and environmentally costly, and as such, their control can be considered a global public good.[2] The complexities and breadth of such threats demand interdisciplinary solutions that address the connections between human and animal health,[3] as well as the underlying environmental drivers that impact health. Traditionally, however, approaches to health have focused on interventions such as human-based clinical treatment, emergency response, or vaccines. Increasingly, there is a push in the global community to move from reductionist, reactionist approaches to more holistic, preventive approaches that rely on systems thinking.[4] One such approach, known as **One Health**, is a growing global strategy that is being adopted by a diversity of organizations and policy makers in response to the need for integrated approaches. This approach can be relevant to a wide range of global development goals, including the Millennium Development Goals themselves, which we explore in the Chapter 30 supplement on studentconsult.com.

In this chapter we define One Health; explore how it is relevant to public health, epidemiology, and medicine; follow its development; learn of its current supporters and applications; and consider implementation strategies for redefining health through transdisciplinary collaboration. Though this exploration of One Health, we hope to introduce a growing cadre of health professionals to a more holistic approach to health that will become increasingly important in the future.

## II. WHAT IS ONE HEALTH?

One Health can be interpreted differently by various groups and tends to serve as a comprehensive framework that has been employed in different contexts.[5] This flexibility can strengthen its applicability rather than narrow its scope. Although different definitions and interpretations exist, a frequently used description follows:

> One Health is [characterized by] the collaborative efforts of multiple disciplines working locally, nationally and globally to attain optimal health for people, animals and our environment.[6]

The One Health approach calls for a paradigm shift in developing, implementing, and sustaining health policies that more proactively engage human medicine, veterinary

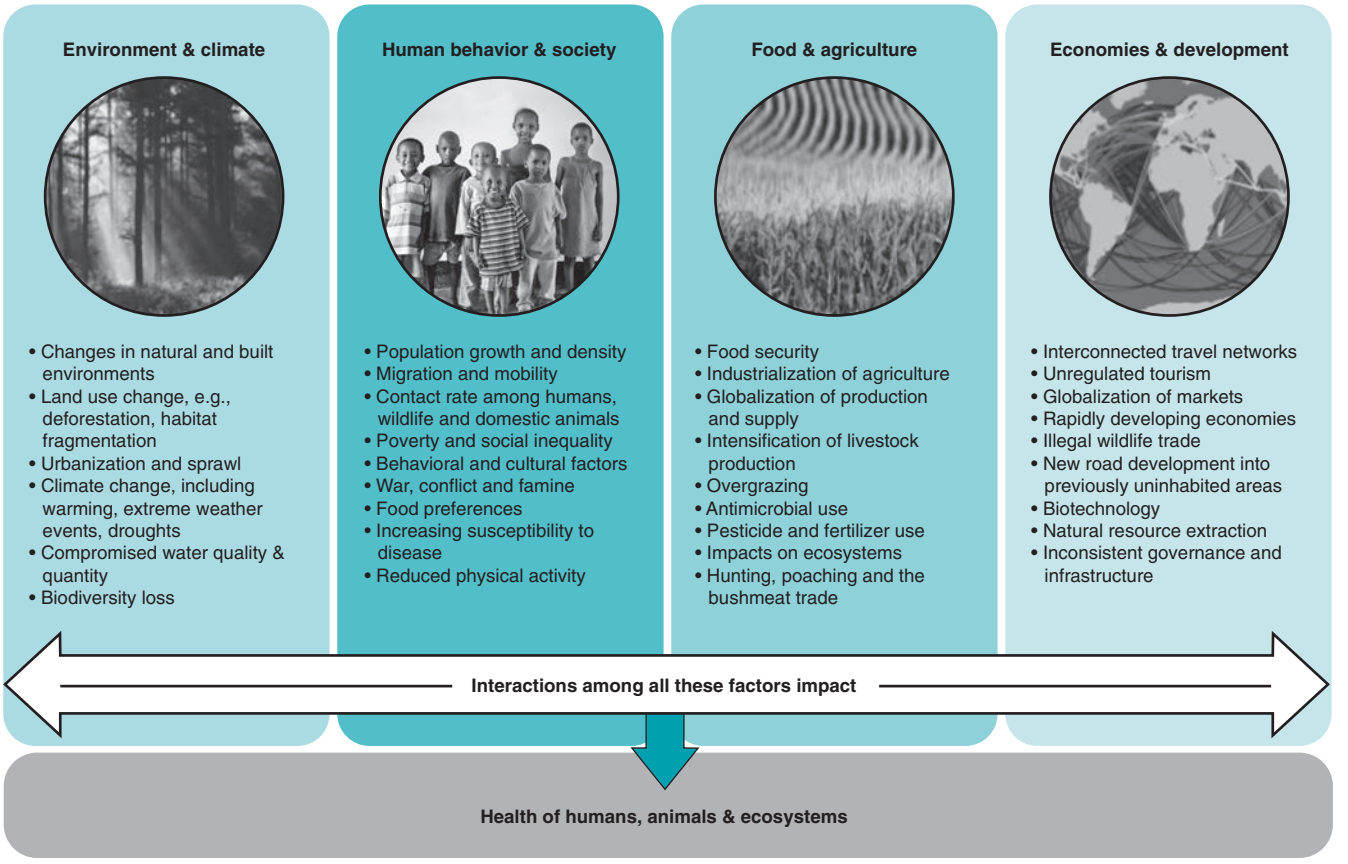



**Figure 30-1** We are undergoing rapid shifts in our environment, in climate, in human behavior, in agriculture, and in economic development. All these factors interact to impact the health of humans, animals, and the environment. (Modified from World Bank: *People, pathogens and our planet: towards a One Health approach for controlling zoonotic diseases*, vol I, Washington, DC, 2010; and Institute of Medicine, National Research Council: *Sustaining global surveillance and response to emerging zoonotic diseases*, Washington, DC, 2009, National Academies Press.)

medicine, public health, environmental sciences, and a number of other disciplines that relate to health, land use, and the sustainability of human interactions with the natural world.[6-10] The use of this multifaceted perspective allows practitioners to work toward optimal health for people, domestic animals, wildlife, and the environment concurrently, over multiple spatial and temporal scales. Whereas some may view One Health as having a singular end goal of optimizing human health, we emphasize here that the maintenance and improvement of animal health and ecosystem functioning are also primary goals of One Health, with their own inherent value separate from their impact on human health.

Past global health interventions have generally tackled a single region or a single disease, but One Health offers an integrative, holistic health *systems* approach that also focuses on "upstream" prevention rather than reactive response. Just as the World Health Organization (WHO) maintains a multifaceted definition of health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity," so too does One Health attempt to address the many different social, environmental, cultural, and physical determinants of human and animal health. Although different interpretations of One Health exist, certain unifying characteristics remain the same across all applications (Box 30-1).

**Box 30-1 Shared Characteristics of One Health Applications**

Goal of optimizing the health of people, animals, and the environment
Prevention-oriented
Collaborative
Transdisciplinary
Multiscale (local, national, global)
Systems-focused
Flexible
Innovative
Synergistic
Added value
Comprehensive
Holistic

## A. Relevance to Epidemiology

One Health shares many of the same fundamental principles as the fields of epidemiology, biostatistics, public health, and preventive medicine and therefore is a relevant topic for these curricula. At its core, One Health calls for a shift from an individual, clinical-based treatment approach to a

more holistic and preventive perspective that considers populations of multiple species and the context of their shared environments. The aim to apply this type of approach from local to global scales is also shared among these fields. The population/prevention focus of public health, epidemiology, and preventive medicine aligns perfectly with a One Health approach. However, One Health can move things a step further by enlarging the spatial, temporal, and organismal scope of these fields. Ultimately, One Health relies on the collaboration of multiple disciplines. Epidemiology, biostatistics, public health, and preventive medicine can serve as foundational disciplines in One Health collaborative networks.

## B. Evolution of the Concept

The One Health concept is actually not a new one; its roots date back to ancient times. The Greek physician Hippocrates (ca. 460–370 BCE) wrote of the importance of the environment for maintaining health in his text, *On Airs, Waters and Places*.[11] Several centuries later, connections between human and veterinary medicine took shape in the 1800s when Rudolf Virchow (1821–1902), a German physician and pathologist known as the "Father of Comparative Pathology," laid the foundations for One Health thinking. He defined the term **zoonosis** (a disease that can be transmitted from animals to people) and stated, "Between animal and human medicine there are no dividing lines—nor should there be." A student of Virchow's, the Canadian physician Sir William Osler (1849–1919), once called the "Father of Modern Medicine," adopted similar ways of thinking about health across both human and veterinary medicine.[4] By the 1940s, this type of collaboration took a more distinct form. James Steele, veterinarian and the first U.S. Assistant Surgeon General for Veterinary Affairs, expanded the role of veterinarians by developing the first Veterinary Public Health program within the Centers for Disease Control and Prevention (CDC) and by incorporating veterinarians into the U.S. Public Health Service. Calvin Schwabe (1927–2006), a leading figure in veterinary epidemiology, re-emphasized the importance of veterinary medicine to human health and promoted the term **One Medicine** in his book, *Veterinary Medicine and Human Health*.[4,12,13]

The field of veterinary public health, which holds that the health of wildlife, domesticated animals, and humans is inherently intertwined, solidified as a result of collaborations among major international organizations such as the WHO and the United Nations Food and Agriculture Organization (FAO).[12,14] As the concept of sustainable development gained traction in the international arena during the late 1980s, a strengthened recognition of the role of the environment surfaced.[4,13] As a result of this trend, some new fields—notably conservation medicine and ecohealth—emerged with a particular emphasis on how the Earth's changing ecosystems affected the health of both animals and humans.[4,14-20] These approaches extended the One Medicine concept to include the whole ecosystem and brought in ideas of sustainable development and socio-ecological influences on health. This represented a move from a more clinical focus to a more holistic view that broadly incorporated the environment and social sciences. This type of perspective contributed greatly to the highly influential and informative **Millennium Ecosystem Assessment,**[21] which further delineated the reliance of human well-being on the environment.

## C. Manhattan Principles on "One World, One Health"

In 2004 the **Wildlife Conservation Society** (WCS) brought together an array of partners to develop an unprecedented collaborative One Health framework to launch the **One World, One Health** initiative.[4,5,8] This launch resulted in the development of the **Manhattan Principles** (Box 30-2), which provide 12 recommendations for "establishing a more holistic approach to preventing epidemic/epizootic disease and for maintaining ecosystem integrity for the benefit of humans, their domesticated animals, and the foundational biodiversity that supports us all."[4,8,22] One World, One Health represented a proactive, collaborative effort among major international agencies and organizations and is seen as an important step in the evolution of One Health.

This type of interagency collaboration has led to several initiatives, including the subsequent 2006 Beijing Principles.[23] Notably, the World Organization for Animal Health (OIE), FAO, and the WHO released a joint strategic concept note to achieve a "world capable of preventing, detecting, containing, eliminating, and responding to animal and public health risks attributable to zoonoses and animal diseases with an impact on food security through multi-sectoral cooperation and strong partnerships."[22,23,24]

Other joint partnerships have emerged. In 2007, the American Veterinary Medical Association (AVMA) and the American Medical Association (AMA) both unanimously and explicitly supported One Health.[6] The AVMA-AMA collaboration called for the formation of a **One Health Commission** to work toward the "establishment of closer professional interactions, collaborations, and educational opportunities across the health sciences professions, together with their related disciplines, to improve the health of people, animals, and our environment" (see Websites list at end of chapter). In addition, the **One Health Initiative** has served as an important global clearinghouse for news and information related to One Health. It collaborates directly with the *One Health Newsletter,* an online quarterly for One Health articles sponsored by the Florida Department of Health. Through the newsletter and website, communication among One Health professionals all over the world has improved significantly.

Through the evolution of the One Health concept, different—yet complementary and related—approaches have emerged. All these approaches capture dimensions of One Health or have played an important role in the development of One Health. Relevant terms and fields complementary to One Health include One Medicine, comparative medicine, "One World, One Health," ecohealth, ecosystem approaches to health, veterinary public health, health in socio-ecological systems, conservation medicine, ecological medicine, environmental medicine, medical geology, and environmental health. Similarities also obviously exist between One Health and major fields such as global health, public health, and population health. As it continues to change and evolve, One Health will be strengthened and further defined, extending in scope and in its ability to address complex health and environmental challenges.[4]

## D. Disciplines Engaged in One Health

Implementing One Health requires the cooperation of experts from numerous disciplines, including but not limited to the following: human medicine, veterinary medicine,

## Box 30-2 Manhattan Principles on "One World, One Health"

Recent outbreaks of West Nile virus, Ebola hemorrhagic fever, SARS, monkeypox, mad cow disease, and avian influenza remind us that human and animal health are intimately connected. A broader understanding of health and disease demands a unity of approach achievable only through a consilience of human, domestic animal, and wildlife health—**One Health.** Phenomena such as species loss, habitat degradation, pollution, invasive alien species, and global climate change are fundamentally altering life on our planet, from terrestrial wilderness and ocean depths to the most densely populated cities. The rise of emerging and resurging infectious diseases threatens not only humans (and their food supplies and economies), but also the fauna and flora comprising the critically needed biodiversity that supports the living infrastructure of our world. The earnestness and effectiveness of humankind's environmental stewardship and our future health have never been more clearly linked. To win the disease battles of the 21st century while ensuring the biologic integrity of the Earth for future generations requires interdisciplinary and cross-sectoral approaches to disease prevention, surveillance, monitoring, control, and mitigation as well as to environmental conservation more broadly.

We urge the world's leaders, civil society, the global health community, and institutions of science to:

1. Recognize the essential link among human, domestic animal, and wildlife health and the threat that disease poses to people, their food supplies, and economies, as well as the biodiversity essential to maintaining the healthy environments and functioning ecosystems we all require.
2. Recognize that decisions regarding land and water use have real implications for health. Alterations in the resilience of ecosystems and shifts in patterns of disease emergence and spread manifest themselves when we fail to recognize this relationship.
3. Include wildlife health science as an essential component of global disease prevention, surveillance, monitoring, control, and mitigation.
4. Recognize that human health programs can greatly contribute to conservation efforts.
5. Devise adaptive, holistic, and forward-looking approaches to the prevention, surveillance, monitoring, control, and mitigation of emerging and resurging diseases that take the complex interconnections among species into full account.
6. Seek opportunities to fully integrate biodiversity conservation perspectives and human needs (including those related to domestic animal health) when developing solutions to infectious disease threats.
7. Reduce the demand for and better regulate the international live-wildlife and bushmeat trade not only to protect wildlife populations but to lessen the risks of disease movement, cross-species transmission, and the development of novel pathogen-host relationships. The costs of this worldwide trade in terms of impacts on public health, agriculture, and conservation are enormous, and the global community must address this trade as the real threat it is to global socioeconomic security.
8. Restrict the mass culling of free-ranging wildlife species for disease control to situations where there is a multidisciplinary, international scientific consensus that a wildlife population poses an urgent, significant threat to human health, food security, or wildlife health more broadly.
9. Increase investment in the global human and animal health infrastructure commensurate with the serious nature of emerging and resurging disease threats to people, domestic animals, and wildlife. Enhanced capacity for global human and animal health surveillance and for clear, timely information-sharing (that takes language barriers into account) can only help improve coordination of responses among governmental and nongovernmental agencies, public and animal health institutions, vaccine/pharmaceutical manufacturers, and other stakeholders.
10. Form collaborative relationships among governments, local people, and the private and public (i.e., nonprofit) sectors to meet the challenges of global health and biodiversity conservation.
11. Provide adequate resources and support for global wildlife health surveillance networks that exchange disease information with the public health and agricultural animal health communities as part of early-warning systems for the emergence and resurgence of disease threats.
12. Invest in educating and raising awareness among the world's people and in influencing the policy process to increase recognition that we must better understand the relationships between health and ecosystem integrity to succeed in improving prospects for a healthier planet.

It is clear that no one discipline or sector of society has enough knowledge and resources to prevent the emergence or resurgence of diseases in today's globalized world. No one nation can reverse the patterns of habitat loss and extinction that can and do undermine the health of people and animals. Only by breaking down the barriers among agencies, individuals, specialties, and sectors can we unleash the innovation and expertise needed to meet the many serious challenges to the health of people, domestic animals, and wildlife and to the integrity of ecosystems. Solving today's threats and tomorrow's problems cannot be accomplished with yesterday's approaches. We are in an era of "One World, One Health," and we must devise adaptive, forward-looking, and multidisciplinary solutions to the challenges that undoubtedly lie ahead.

From Cook RA, Karesh WB, Osofsky SA: *The Manhattan Principles on "One World, One Health": building interdisciplinary bridges to health in a globalized world,* New York, 2004, Wildlife Conservation Society. Available at http://www.oneworldonehealth.org/sept2004/owoh_sept04.html.

public health, environmental science, ecology, environmental health, conservation biology, dentistry, nursing, social sciences, the humanities, engineering, economics, education, and public policy. Although the foundations of the One Health concept originated within the veterinary and human medical professions, there is a strong push toward representation of a wider array of disciplines. One Health is not to be "owned" by certain disciplines. We illustrate the need for the participation of multiple disciplines when approaching health problems with a particularly relevant case study involving West Nile virus (WNV) (Fig. 30-2). When WNV emerged in New York City in 1999, discovery of the outbreak and development of a control strategy depended upon the involvement of multiple disciplines.[25]

## III. BREADTH OF ONE HEALTH

### A. Interdependence of Animal, Human, and Ecosystem Health

Fundamentally, the environment affects how organisms live, thrive, and interact and must be considered in order to achieve optimal health for people and animals.[21,26-28] By

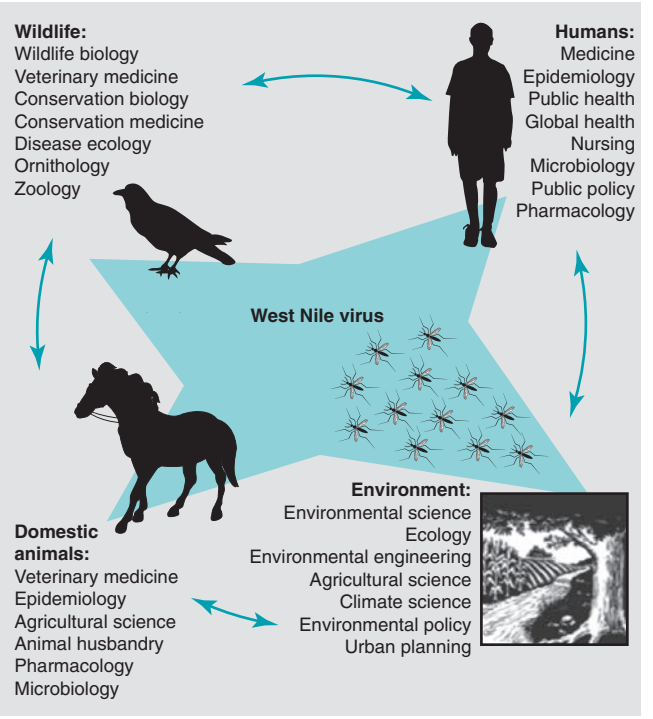



**Figure 30-2 Emergence of West Nile virus (WNV) into the United States.** The collaborative response to WNV in the U.S. provides a perfect case study for the One Health approach. In 1999, physicians noted a strange illness in elderly patients in New York City; simultaneously, veterinary pathologists and epidemiologists were exploring the mysterious deaths of large numbers of crows and exotic birds at the Bronx Zoo. Viral culture and polymerase chain reaction evidence concluded that the infections were related and later confirmed the outbreaks as the first emergence of WNV into the United States via the *Culex* mosquito vector. WNV can infect several wild bird species and a range of mammals, including: horses, squirrels, dogs, wolves, mountain goats, and humans. Combating WNV requires the collaboration of a multitude of disciplines. (From Barrett MA, Bouley TA, Stoertz AH, et al: Integrating a One Health approach in education to address global health and sustainability challenges. *Frontiers Ecol Environ* 9:239–245, 2010. Copyright Ecological Society of America.)

definition, the **environment** includes "all of the physical, chemical and biological factors and processes that determine the growth and survival of an organism or a community of organisms."[29] This definition encompasses many different contexts and scales, ranging from an individual's home environment, to social environments, to regional ecosystems, to the air that we breathe and the climate in which we exist. As such, the definition of environment can include both the *built* environment, such as urban systems, and more unmodified, *natural* ecosystems.

Human and animal well-being relies on the integrity of ecosystems. An **ecosystem** is "comprised of all of the organisms and their physical and chemical environment within a specific area."[29] Ecosystems underpin processes essential to our survival, known as **ecosystem services.**[21] The United Nations **Millennium Ecosystem Assessment,** a global and comprehensive global assessment of the world's ecosystems and what they mean to human well-being, deemed ecosystem services to be the "ultimate foundations of life and health."[21] These services include *supporting* services (nutrient cycling, soil formation, primary production); *regulating* services (climate and flood regulation, disease buffering, water purification); *provisioning* services (food, water, fuel); and *cultural* services (aesthetic, spiritual, mental health) that make the persistence of human and animal life possible[21] (Figure 30-3). Many of these ecosystem services rely on the maintenance of **biodiversity** (including genes, species, and populations) and complex ecological relationships that make possible the growth of food, healthy diets, the development of new medicines, and the regulation of emerging infectious diseases.

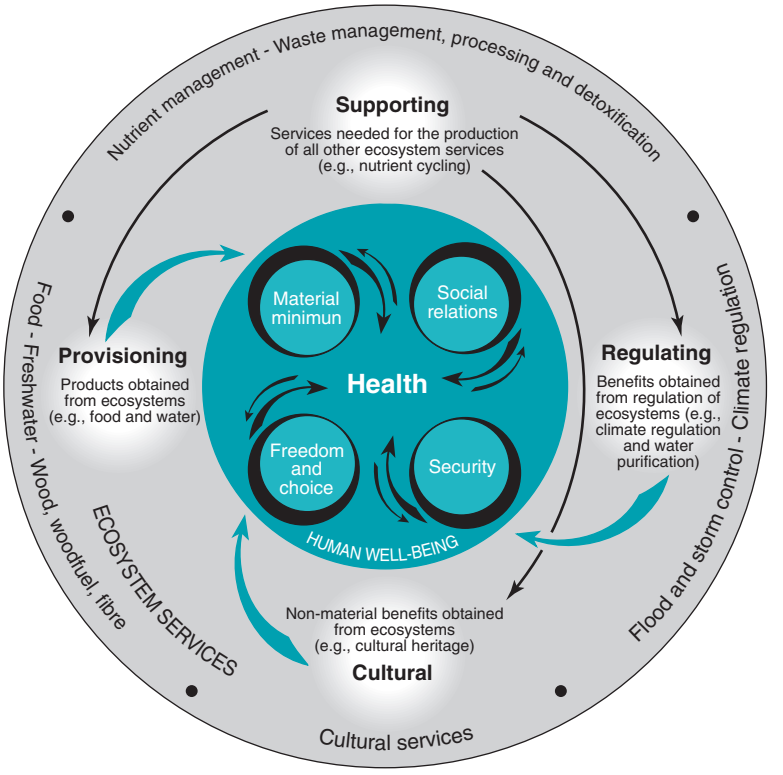
Ecosystems can maintain healthy populations, but when mismanaged or rapidly altered due to human pressure, they can also be associated with disease emergence. Despite the importance of the environment to the preservation of human and animal well-being, we face increasing challenges to the maintenance of healthy ecosystems, including climate change, deforestation, intensification of agricultural systems, freshwater depletion, and resultant biodiversity loss[30,31] (Figure 30-4). In fact, human populations have altered ecosystems more rapidly and extensively over the last 60+ years than during any other period in history, causing some scientists to describe our current geologic time period as the **Anthropocene** ("age of man" or "age of human influence").[21,32] To enable assessment of this change, holistic indicators of ecosystem health (which incorporate environmental, social, and economic aspects of ecosystems) are being developed to assess ecological changes over space and time.[33] **Ecological indicators** can include measures such as water quality, tree canopy cover, soil organic matter, wildlife populations, land-use profiles, and vegetation characteristics.[34]

The growing global human population will continue to increase its need for land, food, and energy, yet already 60% of the essential ecosystem services of the planet are degraded or are under increasing threat. Addressing the environmental factors affecting health is essentially a public health–oriented prevention strategy, as it tackles the upstream drivers of disease. For example, an estimated 24% of the global burden of disease, and more than one third of the burden among children, originates from modifiable environmental causes.[35,36] Such issues are explored in One Health Case Study 1 on studentconsult.com, which examines a particularly salient case highlighting the emergence of Nipah virus in Malaysia caused by a combination of land-use, agricultural, and environmental factors.

## B. Climate Change

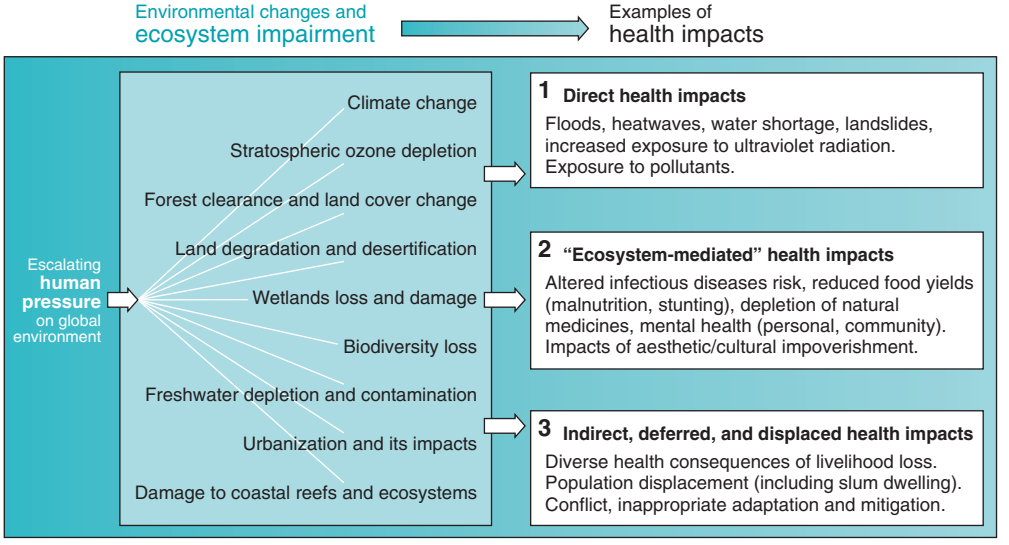
Climate change is one of the most pressing human-driven environmental changes we face. The **Intergovernmental Panel on Climate Change** (IPCC) reported that three main components of climate change will continue to impact ecosystems and health in the future, including warming (1.1°-6.4° C increase in global mean surface temperature by 2100), shifting patterns of precipitation, and increased incidence of extreme climatic events.[37] The exact spatial occurrences of these shifts, as well as the resilience and responses of different ecosystems, are difficult to predict.

When examining the impact of climate change on disease, the picture grows more complex. Climate has affected spatial and temporal patterns of disease globally and has been identified as the greatest threat to global health for the 21st century,[38-40] yet there is still some debate about exactly how




This figure identifies five main aspects of human well-being, with health as the central aspect. Human health is affected directly and indirectly by changes in ecosystems. The basic requirements for human well-being (i.e., material minimum, good social relations, security, freedom, and choice) are inherently connected to health.

**Figure 30-3** Human health relies on essential ecosystem services derived from the environment. (From Corvalan C, Hales S, McMichael A, et al: Ecosystems and human well-being: health synthesis. Report of the Millennium Ecosystem Assessment, Geneva, 2005, World Health Organization. Figure from Rekacewicz P, Bournay E, United Nations Environment Programme/Grid-Arendal.)




This figure describes the causal pathway from escalating human pressures on the environment to ecosystem changes resulting in diverse health consequences. Not all ecosystem changes are included, and some changes can have positive effects (e.g., food production).

**Figure 30-4** Environmental change can degrade ecosystems and negatively affect health. (From Corvalan C, Hales S, McMichael A, et al: Ecosystems and human well-being: health synthesis. Report of the Millennium Ecosystem Assessment, Geneva, 2005, World Health Organization. Figure from Rekacewicz P, Bournay E, United Nations Environment Programme/Grid-Arendal.)

climate change will affect disease burden.[41] Changes in temperature, precipitation, and seasonality can influence infectious disease emergence, incidence, and spread (e.g., as seen with dengue, malaria, cholera).[42,43] These environmental changes can affect pathogen reproduction, abundance, environmental tolerance, virulence, and distributions.[44-47] For example, studies have documented that the chytrid fungus that decimated global amphibian populations partly emerged because of increasing temperatures,[48] and that the impacts of malaria, Ross River virus, plague, hantavirus, and

cholera have been exacerbated by climate change.[39] In addition to disease, the potential health impacts of climate change will be broad and significant in terms of the following: heat and cold effects; wind, storms, and floods; drought, malnutrition, and food security; food safety; water quality; air quality; occupational health; and ultraviolet radiation.[37]

## C. Biodiversity Loss

Land-use change such as deforestation leads to the loss of biodiversity and the increasing interactions of humans, wildlife, and domestic animals,[49-51] which can influence the spread of infectious diseases.[49,52,53] Strong evidence shows that in some vector-borne disease systems, more diverse species communities will reduce the risk of infection.[49,54,55] This pattern, termed the **dilution effect,** works because incompetent reservoir hosts "dilute" the likelihood of disease transmission among vectors and competent hosts.[54-58]

In the classic example of **Lyme disease,** higher levels of forest mammal biodiversity reduced infection risk because a greater proportion of species in more diverse systems were poor reservoirs for the *Borrelia* pathogen (see One Health Case Study 2 on studentconsult.com).

This pattern has also been seen in other vector-borne disease systems such as WNV, leishmaniasis, African trypanosomiasis, Chagas disease, and Rocky Mountain spotted fever.[59,60] In some cases, however, host diversity has also been linked to pathogen diversity. In a global study, zoonotic emerging infectious disease events were correlated with high wildlife biodiversity,[61] and another study found that the number of human pathogens was correlated with bird and mammal diversity in a region.[62]

Deforestation can also affect biodiversity by facilitating access for hunting opportunities. **Hunting** is important to consider for human health in a number of ways: as a source of nutrition, as a risk factor for disease emergence, as a driver of local biodiversity extinctions, and as a supplier for the global wildlife trade. Although hunting does provide valuable protein and micronutrient sources for populations relying on subsistence livelihoods,[63] the process of hunting, butchering, and cooking the animal creates opportunities for body fluid transfer and transmission of diseases from wildlife to humans. In fact, some of the world's most significant emerging diseases have been traced to zoonotic disease transmission via contact through hunting.[64,65] Regardless of whether wildlife is consumed or sold as clothing or ornamentals in wildlife markets, the wildlife trade contributes to the decimation of global biodiversity and the spread of pathogens.[66] A number of pathogens have been transmitted via wildlife trade, both into human populations and into novel wildlife hosts.[66] The global wildlife market is widespread and massive, generating more than an estimated $21 billion annually. The scale and risks associated with the wildlife trade demand an integrated approach to reduce and regulate it.

## D. Food and Water Security

One Health offers new perspectives on addressing issues of food security for increasingly complex and connected global food networks. Factors such as specialization and intensification of livestock production; increasing spatial overlap of humans, wildlife, and domestic animals; deforestation for livestock grazing; globalization of livestock production; and climate change have led to escalating infectious disease occurrence in livestock animal populations,[22,38,57,67,68] raising serious conservation concerns and compromising food security and water quality.[50] Recent livestock diseases within the global food supply have been associated with subsequent occurrences of infectious disease in humans (e.g., bovine spongiform encephalopathy, Rift Valley fever, bovine tuberculosis, H1N1 influenza virus).[69,70] In 2005 alone, 1.8 million people died from food-borne bacterial infections with *Salmonella*, *Campylobacter,* or *Escherichia coli.*[2,71] One Health Case Study 3 on studentconsult.com explores Rift Valley fever and its intersection at the human-animal-environment interface.

Antimicrobial resistance presents another challenge for safe livestock production.[72] Resistant pathogens can cause morbidity and mortality in livestock, large economic consequences, and a danger to public health.[73] These pathogens can infect humans through direct contact with livestock or via unsafe food chains.[74] Other livestock-related diseases have not caused illness in humans, but have led to severe economic losses because of international trade regulations and the mass culling of livestock to prevent the spread of the infection. For example, foot-and-mouth disease in the United Kingdom resulted in the killing of 4 million livestock animals, a loss of £3.1 billion in revenue,[75] which was accompanied by a series of farmer suicides.

Global demand for animal-based protein is predicted to increase by nearly 50% by the year 2020,[76] a worrying forecast for the future of food, water, and ecosystem security worldwide. Agricultural production directly contributes to deforestation and associated land-use changes, further impacting hydrologic and climate systems. Livestock grazing is a main driver of deforestation in the Amazon basin, which boasts about 40% of the world's remaining tropical forests, yet has sustained the world's highest absolute rate of deforestation.[77] This deforestation has a global impact; a reduction in deforestation in the Amazon Basin could result in a 2% to 5% reduction in global carbon emissions.[78]

In light of ongoing agricultural intensification, issues of water quality, quantity, access, and impacts on biodiversity have become paramount worldwide. Widespread land cover change, urbanization, industrialization, and engineering have changed how we use and access water.[79] More than 1 billion people live in river basins vulnerable to the unpredictable effects of climate change, such as storms and droughts. Additionally, 80% of the world's population is under high levels of water insecurity, and an estimated 1 billion people lack access to clean water.[79,80] With water and food security problems growing, One Health can offer more effective solutions by bringing together relevant disciplines. By integrating expertise from agriculture, environmental science, regional planning, and public health, improvements in land-use planning and adaptive management can be achieved.

To highlight the relevance of the One Health approach to a medical and public health audience, we examine its applications to important health problems that a medical professional would confront regularly, in both domestic and international settings. We use the examples of *emerging diseases, neglected diseases, chronic diseases and mental health,* and *biomedical research frontiers* to illustrate the wide applicability of One Health approaches. Throughout these topics, environmental issues such as land use and climate change will be recurring themes.

## E. Emerging Diseases

One of the most widely recognized target areas for One Health approaches is that of emerging and reemerging diseases, particularly those of animal origin. As defined by the WHO, an **emerging disease** is one that has appeared in a population for the first time, while a **reemerging disease** could have been present previously but may be increasing in occurrence and geographic scope.[81] Disease emergence rates have increased dramatically since the mid-20th century; 335 emerging infectious disease events have been identified in humans since 1940, and several rank as leading causes of mortality worldwide, with developing countries assuming a disproportionate burden.[8,61] Of these, more than 60% are zoonotic.[61,82,83] Of these emerging zoonoses, almost three quarters of them have originated in wildlife.[61] One of the most significant and devastating diseases of our time has been traced back to wildlife origins. The human immunodeficiency virus (HIV) evolved from a closely related simian immunodeficiency virus (SIV) found in chimpanzees.[84] HIV causes acquired immune deficiency syndrome (AIDS) and has grown into pandemic proportions within human populations since emergence (see One Health Case Study 4 on studentconsult.com).

Additional important zoonotic diseases and their common hosts are presented in Figure 30-5 on student consult.com. It is of the utmost importance to address the shifting ecological relationships among parasites, pathogens, vectors, and hosts that lead to the emergence of disease.[85,86] A One Health approach can help to accomplish this goal by:

- Integrating and coordinating disease prevention, surveillance, and response.
- Improving communication among human health, animal health, and environmental professionals.
- Addressing the upstream drivers of disease emergence, such as land-use change (e.g., deforestation, agriculture).
- Improving land-use planning to slow deforestation, enhance agricultural efficiency, and better manage livestock numbers and density.
- Adapting to and mitigating the predicted effects of climate change.
- Reducing contact among humans, livestock, and wildlife without compromising normal wildlife movements or wildlife access to critical habitat.
- Educating about safer practices for bushmeat hunting as well as providing alternative protein and income sources.

## F. Neglected Diseases

Emerging diseases often receive global attention and high levels of funding, but many other diseases of equal distribution and consequence go comparatively unnoticed. These diseases, often referred to as **neglected diseases,** include some highly important diseases such as bovine tuberculosis, trypanosomiasis, anthrax, rabies, brucellosis, echinococcosis, cysticercosis, and leishmaniasis.[2,23,81,87] Their *neglected* status often stems from underreporting, poor diagnostics, and a lack of funding. These diseases have the largest effect on poorer communities in the developing world that rely on livestock for their livelihoods.[81] Neglected diseases could be addressed by incorporating One Health surveillance and treatment methods within both human and animal populations, but a lack of funding and communication often prevents this.[81,88] Additionally, improving agricultural practices with expertise from One Health disciplines could reduce infections. One Health Case Study 5 on studentconsult.com explores brucellosis for which mass vaccination of the animal reservoir is a cost-effective and successful public health intervention.

## G. Chronic Diseases and Mental Health

Although most often applied in infectious disease settings, the One Health approach is also relevant for mental health and chronic diseases, such as cardiovascular diseases (CVD), cancer, chronic respiratory diseases, and diabetes. Once associated with high-income countries, chronic diseases now exert a heavier burden within low-income and middle-income countries and continue to increase in prevalence.[89] Global deaths from chronic diseases have more than doubled since 1990 and are expected to cause an estimated 7.63 million deaths in 2020 (66.7% of all deaths).[26,90,91] Because of this impending economic burden, many studies have examined the most effective interventions and recognized the important role of the built and natural environment in managing chronic disease.

One effective strategy for addressing CVD is through physical activity, which has been shown to increase within walkable communities with accessible open spaces for outdoor recreation. Evidence also shows that humans rely on the environment not only for physical activity, but also for psychological, emotional, and spiritual needs.[21,92-97] Contact with nature can reduce stress and improve work performance,[98] as well as enhance emotional and cognitive development in children.[99] As environments degrade, studies have shown that depression can result.[100] In an interesting example within hospitals, patients experienced reduced recovery times and improved outcomes when they could view trees from their hospital room.[101]

From this evidence, policy makers have begun to recognize the important role the environment plays, not just in regulating infectious disease, but also in maintaining healthy communities that can avoid and manage chronic disease. As an example, Australia's national health program has lauded the importance of access to healthy environments as a cornerstone of their general health promotion and prevention strategy.[26] They take an *upstream* approach in health promotion by encouraging citizens to spend time outside and access nature to improve physical activity and prevent disease. They see the benefits of natural environments as a "fundamental health resource" and have documented positive effects on blood pressure, cholesterol, stress reduction, and depression.[26] This type of activity and exposure to nature may have relevance for a range of health priorities, including cancer, injury prevention, mental health, asthma, arthritis, and musculoskeletal conditions, warranting further study.

A One Health perspective can additionally contribute to addressing chronic disease resulting from exposure to unhealthy environments. Chronic diseases such as asthma and cancer may result from prolonged exposure to particulates, chemicals, or toxins in the environment. Animals can play an important role as sentinels for such environmental

**Table 30-1 Different Types of Organisms Serving as Sentinels for Environmental Health Hazards**

| Location | Organism | Sentinel for |
|---|---|---|
| Soil | Earthworms, soil insects, gophers, moles, mice, voles, ground-dwelling birds | Soil contamination |
| Air | Honeybees and other flying insects | Air pollution |
| Plants | Herbivorous animals | Plant contamination |
| Water | Fish, bivalves (e.g., mussels, oysters), gulls, ospreys, seals, some reptiles and amphibians | Toxic chemicals or pollutants in water can accumulate to higher concentrations in animal tissue |
| Homes | Domestic companion animals (e.g., cats, dogs) | Soil contamination, house dust, indoor air pollution, lead |
| Workplace | "Canary in a coal mine" | Chemical or air pollution |

Modified from National Research Council: *Animals as sentinels of environmental health hazards*, Washington, DC, 1991, National Academy Press.

health toxins.[102] **Animal sentinel systems,** in which data on animals exposed to environmental contaminants are monitored and analyzed, have proved extremely helpful in identifying and addressing health hazards for many years.[103] These sentinel systems alert practitioners to hazards in homes, workplaces, agricultural settings, and aquatic and terrestrial ecosystems for risk characterization, hazard identification, dose-response assessment, and exposure assessment.[103] Animal sentinels may include domestic and companion animals, food animals, fish, wildlife, or even insects[103] (Table 30-1). It is important to note that sentinel systems not only benefit human health, but also the health of animals and the environment, because they can target interventions to reduce exposures and improve ecosystem quality. One program that aims to enhance the understanding and use of animal sentinels is the Canary Database of the Yale University Occupational and Environmental Medicine Department (http://canarydatabase.org/). This project accomplishes this goal by making scientific literature and studies of animal sentinels more accessible.

The **human-animal bond** is also an important component of One Health approaches to chronic disease. Evidence shows that the presence of companion animals in the home lowers systolic blood pressure, plasma cholesterol, and triglyceride values in owners.[104] Pet ownership has also been shown to improve survival after serious heart surgery.[105] One should take note, however, that pet ownership can increase the exposure to zoonotic disease due to close bodily contact.

### H. Biomedical Research Frontiers

One Health can contribute to disease prevention, surveillance, and response and expand our research knowledge base. One Health–like approaches have been undertaken in the fields of biomedical research and comparative medicine for some time. These fields have long recognized the connections between humans and animals and have used animal models for developing vaccines, testing medications, and understanding diseases that are similar in humans and animals. The use of animal models has been extremely important when applied to a diverse variety of human health issues, including: mental disorders, infectious disease, stroke, tumor development, and osteoporosis. Studies of animal models of behavior can also elucidate human mental health disorders in terms of how stress, the environment, or social status can influence health. Additionally, the study of nonhuman genomes has facilitated important discoveries within the human genome. From a security standpoint, animal models can assist in preparing for possible bioterrorism.

Beyond animal models of disease, global biodiversity has contributed greatly to the development of novel medicines.[51] Many new species found in the soil, oceans, polar regions, and tropical rainforests have made a significant contribution to drug development. In fact, about half of the 100 most highly prescribed medications in the United States and about half the new drugs approved by the Food and Drug Administration (FDA) have been developed from nature.[106] New species continue to be discovered in nature every year. For example, despite 250 years of species classification and over 1.2 million species already catalogued, studies suggest that 86% of terrestrial species and 91% of marine species remain undiscovered.[107] Increasing ecosystem degradation and land-use change threaten to make these species discoveries impossible, which among other things would be a devastating loss to medical and pharmaceutical advancement. As such, it is important for the medical community to enhance public recognition of the importance of maintaining biodiversity and ecosystem quality.

## IV. GOALS AND BENEFITS OF ONE HEALTH

Overarching benefits of the collaborative, integrative One Health approach are expected yet now need to be objectively evaluated through further research and economic analyses. Projected benefits include a synergy of systems, improved surveillance and preparedness, a shift toward prevention, and ultimately, economic savings. One Health is *synergistic,* as it aims to shift the focus from single diseases to strengthening public and animal health systems, while also recognizing the environmental and social drivers of health.[5] To achieve this synergy, there must be a delicate balance between improving collaboration and cooperation while also acknowledging the distinct objectives and management principles of each discipline involved. If One Health is successfully implemented, there should be improved reach and efficiency in logistics, the enhanced provisioning of services globally, and the strengthening of health systems.[108,109]

As a benefit of this integration, global health surveillance and preparedness should improve.[4,85] For example, an integrated One Health system could ultimately reduce the lag time for detecting emerging diseases, as well as improve response and, as importantly, prevention.[4] Recent outbreaks of emerging infectious diseases, including avian and swine influenza, WNV, and severe acute respiratory syndrome (SARS), have captured global attention with their significant effects on economies, biodiversity, and public health.[50,61,110,111] The World Bank estimates that infectious disease outbreaks over the last decade have cost more than $200 billion in direct and indirect costs, and a potential H5N1 or other pandemic could cost $3 trillion.[2,69,85,112]

The economic burden of emerging zoonoses underscores the urgent need for collaborative disease surveillance in both animals and humans, improved communication, integrated health systems, as well as a shift toward preventive actions against disease emergence.[113,114]

This type of integration would offer benefits in particular at the human-wildlife-livestock interface.[9] It would provide economic savings by adding value and allowing for cost-effective financing of programs that more efficiently address multiple objectives, as explored in the brucellosis case study[4,13] (see One Health Case Study 5 on student consult.com). As additional salient examples of the benefits of this type of integration, we briefly outline a few more programs that have addressed human and animal disease cooperatively. The HALI project in Tanzania simultaneously investigates the medical, ecological, socioeconomic, and policy issues that influence health outcomes caused by diseases at the human-animal interface, such as *M. bovis, Brucella, Salmonella, Cryptosporidium, Giardia, E. coli,* and *Campylobacter.*[115] In Chad, joint human and cattle vaccination programs have proved successful[116] and have also been shown to be more cost-effective for addressing brucellosis than just human or animal control alone.[13,117] Several other studies demonstrate how control of an animal reservoir for disease can ultimately save money on human public health interventions, as seen with sleeping sickness in Uganda[118] and *Schistosoma japonicum* in China.[119-121] To further explore *S. japonicum* and the environmental, human, and animal health consequences of the construction of the Three Gorges Dam, see One Health Case Study 6 on studentconsult.com. Despite the potential cost savings of integrative approaches, this type of intervention is unfortunately not commonly implemented because of a lack of funding in resource-poor countries or the absence of a veterinary perspective in public health planning.[23]

## V. INTERNATIONAL, INSTITUTIONAL, AND NATIONAL AGENCY SUPPORT

One Health has raised awareness of the increasing connections among the health of humans, animals, and the environment; increased scientific debate; fostered new research paradigms; and enhanced cooperation for disease surveillance and response.[4,23,116] Even before the current decade, the concepts behind what later became known as One Health began receiving attention from a diverse array of government agencies, nongovernmental organizations (NGOs), intergovernmental agencies, educational institutions, professional associations and others, and a number of different programs have evolved.[65,122] The strength of the movement has originated from consensus, shared interests, and common goals, and the weight and legitimacy of its supporters also lend it strength. The diverse stakeholders involved in the growth of One Health stem primarily from three groups at different scales[5]:

- International organizations that provide global leadership and buy-in
- Research networks and NGOs that provide analysis and expertise
- National agencies that provide political leadership and some funding

Intergovernmental organizations and agencies, including OIE, WHO, FAO, UN System Influenza Coordination Unit, World Bank, and U.S. agencies such as the United States Agency for International Development (USAID) and CDC, have come together in support of One Health around issues requiring cooperation, such as infectious disease monitoring and crisis management.[5]

Through partnerships built in part on these existing organizations' working relationships, integrative potential has been leveraged. Many research organizations, NGOs, professional associations, and national agencies have also taken the lead in building support for One Health through conferences, journal publications, and newsletters. Currently, these diverse agents are working together to determine how to operationalize One Health without duplication of effort. The Stone Mountain meeting focused on identifying clear steps toward One Health operationalization and implementation and has resulted in the creation of six ongoing working groups.[123] Several other key international meetings have been instrumental in moving toward this goal. Notably, the WHO, OIE, FAO, World Bank, and USAID came together with national partners through a series of international ministerial and interministerial meetings to focus on integrated preparedness for H5N1 influenza. These international meetings have represented a new, elevated level of cooperation among all these stakeholders.[2] Additionally, the International One Health Congress provided one of the first open conference opportunities to bring together professionals working across One Health–oriented disciplines. These meetings have provided a forum for scientific inquiry and a platform for discussion on how to operationalize One Health.

## VI. ENVISIONING ONE HEALTH IN ACTION

### A. Integrative Approaches to One Health

Now that we have explored contexts in which One Health is relevant, let's explore a few situations in which a One Health approach has been designed and implemented from the ground up. These programs are all explored in the Chapter 30 Supplement on studentconsult.com. One pioneering program of the Wildlife Conservation Society is Animal & Human Health for the Environment And Development (AHEAD), a landscape-level approach to addressing challenges at the interface of wildlife health, domestic animal health, human health and livelihoods, and environmental stewardship.[10] Another groundbreaking One Health program is PREDICT, part of USAID's Emerging Pandemic Threats Program that is building a global early-warning system. Also, the innovative HealthMap program uses technology to facilitate and visualize the integration of human and animal disease surveillance around the globe.[124] (See the Websites list.)

### B. Implementation of One Health Framework

The One Health perspective offers a wealth of benefits for enhancing approaches to global health and sustainability challenges, but how will it be more consistently implemented? Although opinions and strategies differ, certain goals are shared across borders and disciplines. These

goals include the enhancement of: research, communication, cooperation and priority setting across institutional lines, integrated surveillance, shared data systems, rapid-response mechanisms, preparedness and prevention, incentive frameworks, both horizontal and vertical health systems, institutional frameworks, methods for education, and joint funding.[2]

To accomplish these goals, a number of changes must occur to mainstream One Health.[125] We briefly discuss the communication, institutional, technical, and educational steps needed to operationalize the One Health approach on studentconsult.com.[5,85] In this online section, we provide recommendations for redesigning a more integrative and dynamic educational system, including the recognition of several "hot spot" areas of potential One Health collaboration across the United States.[126]

## VII. SUMMARY

### A. Growing Need for One Health Approaches

Issues of global environmental change, global health, emerging disease, and sustainability present some of the most complex and far-reaching challenges of the 21st century. Individual disciplines cannot address these issues in isolation, and the potential economic, health, and environmental consequences of inaction are enormous. One Health offers a logical path forward by recognizing the interconnected nature of human, animal, and ecosystem health in an attempt to inform health and environmental policy, expand scientific knowledge, improve health care training and delivery, improve conservation outcomes, identify *upstream* solutions, and address sustainability challenges.

One Health uniquely focuses on upstream approaches that tackle the root causes of global health and environmental challenges. By focusing on prevention, a One Health approach could, for example, not only reduce the response time to infectious disease outbreaks, but also predict and ideally prevent such disease emergence from occurring. It can also improve disease surveillance and response, strengthen health systems, enhance public health interventions, direct new avenues of research to enhance our understanding of health and the environment, improve vaccine development, augment medical care, strengthen conservation efforts, reinvigorate educational systems, and avoid large economic consequences of foreseeable and preventable disasters.[127,128] One Health can enhance strategies for sustainable development and conservation, especially surrounding protected areas, where health issues are relevant to threatened wildlife populations, people, and their domestic animals.[7,9]

We are at a turning point in which the sustainability of future human generations is increasingly reliant on proactive, earnest global stewardship.[67] Although challenges and barriers to realization of One Health certainly exist, this is an exciting and critical time in which to develop these collaborative, cross-sectoral approaches. Professionals from diverse disciplines are working together now to find collaborative solutions, at local, regional, and global scales.[38,129,130] We urge you to get involved.

### B. Integrating One Health into Your Professional Career

One Health can add dynamism and broader relevance to health-related careers. As you enter your professional career, look for the following opportunities to become involved:

- Seek out local One Health research groups and seminar series.
- Attend One Health training workshops.
- Develop international, cross-sectoral professional networks.
- Develop collaborative, transdisciplinary research projects and grants.
- Publish transdisciplinary papers in traditional "unidisciplinary" journals (e.g., *JAMA*).
- Publish in transdisciplinary journals (e.g., *EcoHealth, Emerging Infectious Diseases, Environmental Health Perspectives, PLoS* journals).
- Attend transdisciplinary conferences (e.g., EcoHealth, AAAS, International One Health Congress).
- Participate in ongoing interdisciplinary education opportunities.
- Stay open to the importance of other perspectives on health and the environment.
- Keep updated on One Health progress through newsletters and online (see Websites).

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www.wcs.org [Wildlife Conservation Society]

CHAPTER 30 SUPPLEMENT

# One Health: Interdependence of People, Other Species, and the Planet

Meredith A. Barrett and Steven A. Osofsky

## APPLICATIONS OF ONE HEALTH TO MILLENNIUM DEVELOPMENT GOALS

The One Health approach can provide integrated and collaborative solutions to a number of important global health and sustainability challenges. As an example of its widespread applicability, we highlight the **Millennium Development Goals** (MDGs, www.un.org/millenniumgoals), one of the most globally accepted development metric paradigms. The United Nations spearheaded the MDGs to address poverty, education, equity, mortality, sustainability, and health. The eight targets for the MDGs address wide-reaching and complex global issues, and as such, they require multisectoral, integrated approaches. Adopting a One Health approach could help in achieving the MDGs by strengthening cross-sectoral collaboration and approaching problems with a preventive focus.[1-3] In fact, six of the eight MDGs could benefit from a strategic application of the One Health approach (Table S30-1).

**Table S30-1 Millennium Development Goals as Defined by the United Nations**

| Millennium Development Goals | Potential Benefits of One Health Approach |
|---|---|
| **Goal 1:** Eradicate extreme poverty and hunger.* | Improved crop agriculture and livestock production; better understanding of how climate change will affect food security. |
| **Goal 2:** Achieve universal primary education. | Indirect relevance. |
| **Goal 3:** Promote gender equality and empower women. | Indirect relevance. |
| **Goal 4:** Reduce child mortality.* | Reduce diarrheal infections, one of the biggest killers of children, by improving water quality and food safety. |
| **Goal 5:** Improve maternal health.* | Improve water quality and food safety; reduce use of biomass for fuel and promote use of alternative, cleaner stoves. |
| **Goal 6:** Combat HIV/AIDS, malaria, and other diseases.* | Understand the environmental and behavioral drivers of disease emergence; approaches to vector control; and relevance of animal reservoirs of disease. |
| **Goal 7:** Ensure environmental sustainability.* | Reduce the rate of environmental degradation; incorporate more efficient, less costly, and less environmentally damaging agricultural and industrial methods; recognize the importance of addressing climate change. |
| **Goal 8:** Develop a global partnership for development.* | Integrate health, environmental stewardship, energy, trade, business, and public infrastructure systems to improve health. |

*These goals could benefit from applications of a One Health approach.

### One Health Case Study 1

### *Deforestation, Intensive Livestock Production, and Nipah Virus Emergence*[4]

An outbreak of a novel paramyxovirus, the Nipah virus, struck Malaysia in late September of 1998. Although the virus is native to fruit bats (Pteropodidae family),[5] unusually close contact between bats and swine during 1998 allowed the virus to jump species. Those in contact with infected swine quickly became ill, and the virus rapidly spread across peninsular Malaysia and into Singapore through the transport of infected pigs (Fig. S30-1). By the time the outbreak was contained in May 1999, 105 individuals had died, most of whom were directly involved with swine farming. Additionally, more than 1.1 million pigs had been slaughtered at a cost of $97 million, effectively devastating Malaysia's swine industry.

Retrospectively, it was determined that ineffective control measures and poor disease surveillance greatly exacerbated the spread and severity of disease. The novel exposure of humans to Nipah virus was caused by a unique combination of environmental, animal, and human factors: deforestation, forest fires, and a drought in 1998 are thought to have forced fruit bats to concentrate in fruit orchards in northern Malaysia.[6,7] The proximity of these orchards to pig nurseries allowed for the spillover of Nipah virus from bats to pigs,[8] and unprotected physical contact between pigs and pig farmers allowed the virus to rapidly infect humans. Unfortunately, the disconnect among Malaysia's human, animal, and environmental health entities made recognizing Nipah virus as the causative agent of the outbreak particularly complicated for the Malaysian government. A One Health approach involving interdisciplinary collaborations among these entities could have resulted in more rapid identification of the outbreak and implementation of more suitable control measures, saving lives.

Fruit bats are native to several countries in or proximal to Southeast Asia, including Indonesia, Madagascar, India, Bangladesh, China, Thailand, Cambodia, Papua New Guinea, and Australia. Bats in all these countries have tested seropositive for either Nipah virus or Hendra virus, a closely related paramyxovirus also capable of infecting humans.[9] There is potential for overlap in distribution of Hendra and Nipah viruses and for pteropid bats to act as vectors for long-distance transmission to humans or animals.[10] Although the

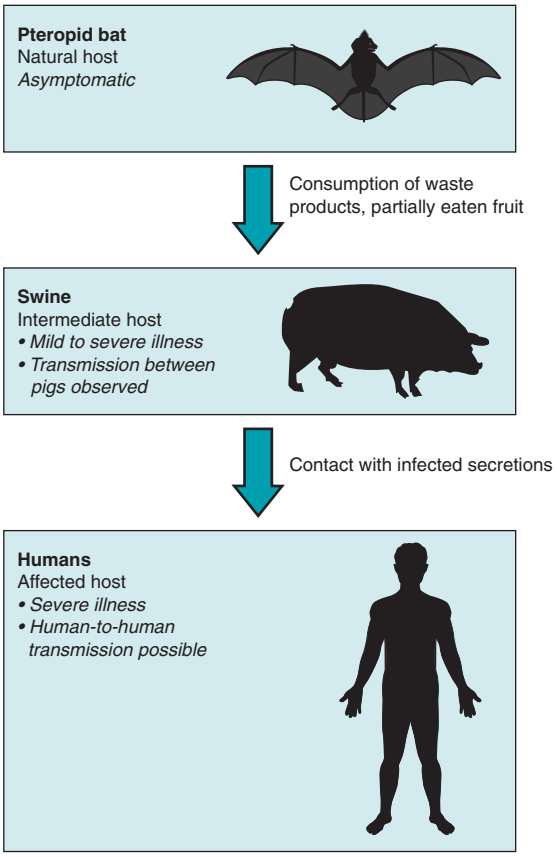


**Figure S30-1** The Nipah virus transmission cycle in Malaysia, 1998-99. (Modified from Nadimpalli M, Akoroda U, Williams JT: Nipah virus in Malaysia, 1998-99: a One Health perspective. In Barrett MA, Sackey-Harris M, Stroud C, editors. *Applications of the One Health approach to current health and sustainability challenges: an educational resource*, vol 1, Durham, NC, Duke University, University of North Carolina, North Carolina State University [In press].)

1998-99 Nipah virus outbreak affected only Malaysia and Singapore, future outbreaks of Nipah virus could occur in any country within the geographic range of these bats. Pteropid bats migrate in response to available food sources, and their movements do not recognize national boundaries. Human outbreaks have recently occurred in both India and Bangladesh, for example, from the consumption of contaminated fruit and fruit products.[9] A One Health approach could be invaluable to any country dealing with or hoping to prevent an outbreak of Nipah virus in the future.

Note: The text in this case study was modified with permission from Nadimpalli M, Akoroda U, Williams JT: Nipah virus in Malaysia, 1998-99: a One Health perspective. In Barrett MA, Sackey-Harris M, Stroud C, editors: *Applications of the One Health approach to current health and sustainability challenges: an educational resource*, vol 1, Durham, NC, Duke University, University of North Carolina, North Carolina State University [In press].

## ONE HEALTH CASE STUDY 2

# *Biodiversity Loss, Land Use, and Lyme Disease*[11]

## ANIMAL-HUMAN-ECOSYSTEM DYNAMICS

Lyme disease is the most prevalent vector-borne disease in the temperate zone. It is a zoonosis caused by the bacterium

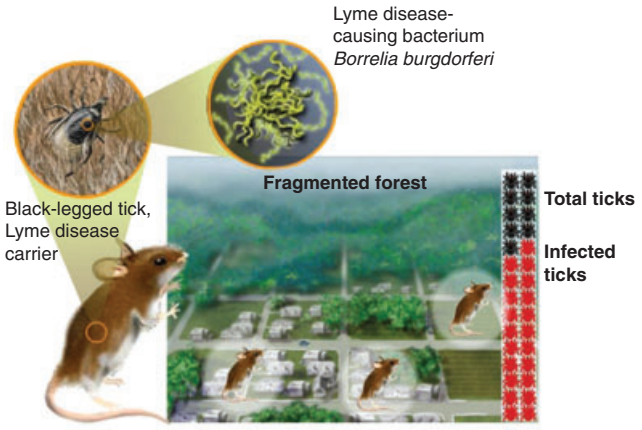


**Figure S30-2** Lyme disease infection is influenced by complex interactions among people, wildlife biodiversity, and the effects of environmental change. (Modified from Veterinarians Without Borders: One Health for One World: a compendium of case studies, 2010. Courtesy Nicolle Rager-Fuller, National Science Foundation.)

*Borrelia burgdorferi*. The bacteria are maintained in transmission cycles involving tick vectors and wild animal hosts (rodents, birds, and other wild mammals).

Lyme disease is transmitted to humans and domesticated animals by certain species of ticks from wildlife. Although the geographic range of the bacterium causing Lyme disease has expanded and contracted for millennia with environmental change (i.e., interglacials) in Eurasia and North America, the Lyme epidemic in the United States was likely caused by human-induced changes in land use. One example includes farmland reverted to woodland as the result of changing economics and policy in agriculture. This caused increased deer and tick populations and a culture of outdoor recreational activity in these woodlands, which enabled greater interaction of people with infected ticks. As development increased forest fragmentation, exposure of humans to infected ticks also increased (Fig. S30-2). Evolution of *B. burgdorferi* for different reservoir hosts has resulted in genetic variants that cause different disease entities in humans.[11a]

Changes to biodiversity are likely to have impacts on Lyme disease risk by affecting the abundance and range of reservoir hosts in any given locality. Although this has become a paradigm for exploring conservation and infection disease risk relationships, the direction of effect is as yet not completely predictable. Emergence of Lyme disease risk in North America is being driven by a warming climate, which enhances the survival of the tick vector.

## RESPONSE AND CONCLUSIONS

Understanding the environmental determinants of Lyme disease helps to predict the risk of exposure and assists public health professionals in making decisions. For instance, communication among managers of parklands, the general public, hunters, dog owners, and public health officials allows disease awareness to be raised, decreasing chances of

an epidemic in humans. Understanding links between ecological processes and disease entities allows for more precise understanding of the links among animal, environmental, and human health.

Recent rapid changes in climates, landscapes, and how people interact with their environment have been associated with the emergence of more severe diseases. Thus, populations who live near changes in land use (urbanization, encroachment into wilderness, abandonment of farms, intensification of agriculture) need to be monitored for changes in health outcomes. By involving local people in surveillance and response and investigating their concerns seriously, policy makers are less likely to be surprised by new diseases and will be more able to respond quickly and effectively.

Note: The text in this case study was modified with permission from Veterinarians Without Borders: *One Health for one world: a compendium of case studies*. Victoria, Canada, 2010.

## ONE HEALTH CASE STUDY 3

### *Rift Valley Fever at the Interface of Humans, Domestic Animals, and the Environment*[11]

### THE DISEASE

Rift Valley Fever (RVF) is a zoonotic disease affecting mainly sheep and cattle in the Rift Valley in Africa, and more recently the Middle East. It is caused by a mosquito-borne virus. The severity and degree of clinical signs may vary according to age or breeds of the animals affected, with infections usually inapparent or mild in adults but with high mortality rates in newborn animals and abortions in pregnant animals. The majority of animal infections result from infected mosquito bites, whereas most human infections are caused by direct or indirect contact with the blood or organs of infected animals. RVF in humans is usually asymptomatic or characterized by an acute fever. However, although 99% of infections are subclinical, the numbers of deaths can be high because of the sheer numbers of people infected. The virus infects the vector at every stage of its life cycle, and infected mosquito eggs can lie dormant in the ground for long periods in semi-arid areas. Hatching is stimulated by wet weather, and the local flooding that follows allows water to accumulate in pools that provide an ideal mosquito breeding ground. Most species of the *Aedes* mosquito rarely feed on humans, but when large numbers of animals become infected through mosquito bites, this can lead to direct transmission to humans by infected blood and tissue (e.g., during butchering) and also mass transmission by secondary mosquito vectors that become infected by biting livestock.

### ANIMAL-HUMAN-ECOSYSTEM DYNAMICS

Identified in the 1930s in Kenya, RVF virus now circulates in many other African countries, as well as on the Arabian Peninsula, where epizootics and associated human cases have been reported. Larger epidemics appear to occur about every decade. Climate change could have a major impact on the occurrence and distribution of the disease due to more frequent extreme weather events and the impact of these events on the biology and geographic distribution of arthropod vectors. Additionally, it is argued that the international trade of livestock and large-scale human movements, which have both expanded during the past 40 years, are important contributory factors. RVF, being a transboundary zoonotic infection associated with human health impacts and large losses of livestock assets, is complicated by climatic changes commonly affecting vulnerable African communities. Poor pastoralists, already facing increased climate-related hazards such as droughts and floods and lacking adequate support policies, may be most seriously affected.

### RESPONSE AND CONCLUSIONS

Prediction of outbreaks of RVF can be made using satellite imaging because vegetation responds to increased rainfall, and variations in vegetation can be easily measured by satellite. In East Africa, vegetation index maps have been used together with ground data to monitor vector populations and RVF viral activity, and a correlation between these two parameters has been established. Vegetation measurements can be used in a more proactive way to forecast RVF before cases reach epidemic proportions. Such predictions can improve the timeliness of action to identify, prevent, and/or control the disease by implementing vector control. Steps that can be taken to prevent amplification of the virus in livestock include vector control and targeted, hygienic mass vaccination of animals. Strengthening global, regional, and national early-warning systems and coordinating subsequent prevention and intervention measures will be crucial.

Note: The text in this case study was modified with permission from Veterinarians Without Borders: *One Health for one world: a compendium of case studies*. Victoria, Canada, 2010.

## ONE HEALTH CASE STUDY 4

### *Origins of Human Immunodeficiency Virus*

Two types of human immunodeficiency virus (HIV) can infect humans: HIV-1, which causes the majority of HIV infections worldwide, and HIV-2, which is largely geographically confined to West Africa.[12,13] HIV-1 has infected more than 60 million people worldwide and has resulted in more than 25 million deaths.[14] Both types have been traced back to simian immunodeficiency viruses (SIVs) endemic in more than 26 different species of nonhuman primates[15] (Fig. S30-3). The pandemic strain of HIV-1 (group M) is most closely related to SIV documented in chimpanzees and originated from one distinct cross-species transmission event. HIV-2 is most closely related to SIV from wild sooty mangabeys. Based on banked human blood, tissue samples and estimates of viral mutation rates, scientists have calculated that the HIV-1 (group M) jump from chimpanzees to humans occurred in central Africa during the late 19th or early 20th century, a time of rapid urbanization and social change in the region.

The mechanism for this jump has been a subject of controversy and discussion, but the most plausible explanation for this cross-species transmission points to *bushmeat hunting*.[12,16] During the hunting and butchering process, the likelihood for body fluid exchange, with the resulting potential for SIV infection, is much higher than would otherwise

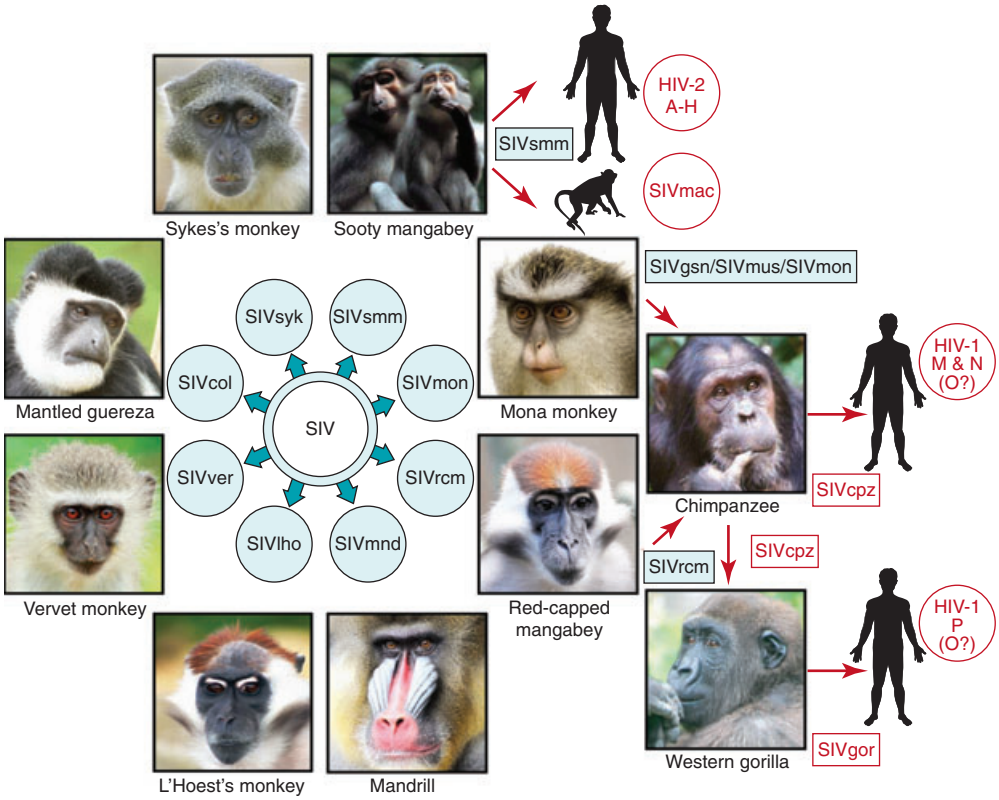


**Figure S30-3** Human immunodeficiency virus (HIV) strains are derived from simian immunodeficiency virus (SIV) types from one species of monkey, one species of chimpanzee, and one species of gorilla. (Modified from Sharp PM, Hahn BH: Origins of HIV and the AIDS pandemic. *Cold Spring Harbor Perspect Med* I(I), 20II.)

be the case. However, a single transmission does not guarantee a subsequent spread within the human population. The virus must be able to adapt to the new host and be transmissible from human to human. To reach global pandemic status, the virus must be dispersed widely. The HIV pandemic resulted from a complex interplay of ecological, biologic, and social factors. Rapid global shifts in urbanization, globalized trade and travel, economic development, behavioral changes, immigration, and sexual behaviors facilitated the emergence and spread of HIV infection.

## ONE HEALTH CASE STUDY 5

## *Brucellosis: Vaccinating Animals for Human Health*[11]

### THE DISEASE

Brucellosis is one of the world's major zoonoses, alongside bovine tuberculosis and rabies. *Brucella* infection is endemic in humans and livestock in Mediterranean countries. It is also present in Asia, sub-Saharan Africa, and the Americas. It can have a considerable impact on human and animal health, as well as wide socioeconomic impacts, especially in countries in which rural income relies largely on livestock breeding and dairy products. Human brucellosis, a long lasting debilitating disease, is caused by exposure to livestock and livestock products. The most important causative bacteria are *Brucella melitensis* (in small ruminants) and *B. abortus* (in cattle). Infection can result from direct contact with the bodily fluids of infected animals and can be transmitted to consumers through raw milk and milk products. Human-to-human transmission of the infection does not occur. In animals, brucellosis mainly affects reproduction and fertility by mass abortion and reduces milk yield.

### ANIMAL-HUMAN-ECOSYSTEM DYNAMICS

Except for some of the Mediterranean countries, industrialized countries have controlled or eliminated brucellosis and other zoonoses by massive state interventions, including mass vaccination and test-and-slaughter campaigns. These operations were successful when veterinary services performed well and when farmers were compensated financially for culled animals. Many developing countries lack the financial means to engage in such operations, despite reasonably well-performing veterinary services. The question remains: can zoonotic disease control be cost-effective in low-income and transition countries?

### RESPONSE AND CONCLUSIONS

In Mongolia and central Asian countries, human brucellosis reemerged as a major but preventable disease in the early 1990s. After consultations with experts, the World Health Organization (WHO) wanted to investigate whether mass vaccinations of animals would save money for the public health sector. A One Health conceptual approach was designed, which included a cross-sectoral economic analysis estimating the economic benefit and cost-effectiveness of mass brucellosis vaccination. The intervention consisted of a

planned 10-year annual livestock mass vaccination campaign of small ruminants and cattle. Estimated intervention costs were $8.3 million, and the overall benefit was $26.6 million across animal health and public health sectors. This results in a present net value of $18.3 million and a benefit-to-cost ratio for society of 3.2. If the costs of the intervention were shared between the various sectors in proportion to the economic benefits each sector received, the public health sector would contribute 11% to the costs of the vaccination program.

### POLICY IMPLICATIONS

If costs of vaccinating livestock are allocated proportionally to all benefits, this type of intervention is cost-saving and cost-effective for the agricultural and the public health sectors. With such an allocation of costs in proportion to benefits per sector, brucellosis control becomes one of the most cost-effective interventions (<$25 per disability-adjusted life year [DALY] gained) in the public health sector.

Note: The text in this case study was modified with permission from Veterinarians Without Borders: *One Health for one world: a compendium of case studies*. Victoria, Canada, 2010.

#### One Health Case Study 6

### *Schistosomiasis and Three Gorges Dam in China*[17]

Schistosomiasis affects up to 200 million people annually, with the heaviest burden among the world's poor reliant upon agricultural livelihoods. Traditional agricultural practices, coupled with unstable access to clean water and sanitation, heighten daily exposure to the parasite and increased rates of infection. In 1994, China started construction of the Three Gorges Dam to generate energy and control flooding along the Yangtze River. The dam stretches more than 2 km across the Yangtze River and creates a reservoir upstream estimated to be over 410 miles long. Despite the utility of the new resource, its construction was not without consequences. The dam displaced more than 1.3 million people and disturbed local terrestrial and aquatic ecosystems.

One organism directly affected by the dam's construction was the *Oncomelania* snail, an intermediate host for *Schistosoma japonicum.* As a result of new upstream reservoirs and irrigation practices, the snail's habitats have expanded to regions where *S. japonicum* had been previously controlled. Subsequently, there has been a reemergence of the parasite in areas around the reservoir. To add complexity to this issue, *S. japonicum* can be amplified by the presence of the water buffalo and cattle, which both serve as significant reservoir hosts.

The Chinese government launched an integrated control program to lower the incidence of *S. japonicum* that included physicians, veterinarians, environmental scientists, and parasitologists. The program comprised mass chemotherapy using praziquantel, mass deworming of cattle and water buffaloes, as well as snail control. The program also focused on providing access to clean water and sanitation to break the chain of transmission. The program has led to a drastic reduction in the incidence of *S. japonicum* in both animal and human populations.

The integrated control program was considered successful, but it is not clear whether a more proactive, upstream One Health approach incorporated as part of the original planning for the dam could have prevented some of the events that led to a disease cascade impacting so many people and animals in the region. In reaction to megaprojects such as this dam, there is growing support for requiring not only *environmental* impact assessments, as required in the United States by the National Environmental Policy Act, but also *health* impact assessments for national policies and projects. (See the Health Impact Project for further information, www.healthimpactproject.org/hia.)

Note: The text in this case study was modified with permission from Niyonzima N, Shifflett SD: The Yangtze River Dam and schistosomiasis in China: a One Health case study. In Barrett MA, Sackey-Harris M, Stroud C, editors: *Applications of the One Health approach to current health and sustainability challenges: an educational resource,* vol 1, Durham, NC, Duke University, University of North Carolina, North Carolina State University [In press].

## INTEGRATIVE APPROACHES TO ONE HEALTH

#### One Health in Action 1

### *Animal & Human Health for the Environment And Development*

The Wildlife Conservation Society (WCS) and a consortium of organizations launched the Animal & Human Health for the Environment And Development (AHEAD) program at the 2003 International Union for the Conservation of Nature (IUCN) World Parks Congress in Durban, South Africa. By assembling top veterinarians, ecologists, biologists, social and economic scientists, agriculturists, wildlife managers, public health specialists and others from across East and southern Africa, WCS, IUCN, and a range of partners tapped into some of the most innovative conservation and development thinking on the African continent. Since then, a range of programs addressing conservation, health, and concomitant development challenges have been launched with the support of a growing list of implementing partners and donors who see the intrinsic value of what WCS has called the "One World, One Health" approach.

A convening, facilitative mechanism, AHEAD is working to create environments that allow different and often competing sectors to find collaborative ways forward to address challenges at the interface of wildlife health, livestock health, and human health and livelihoods. The program convenes stakeholders; helps delineate conceptual frameworks to underpin planning, management, and research; and provides technical support and resources for projects identified as priorities. AHEAD recognizes the need to look at health and disease not in isolation but within a given region's socioeconomic and environmental context.

Historically, governments, nongovernmental organizations, the aid community, and academia have not holistically addressed the landscape-level nexus represented by the triangle of wildlife health, domestic animal health, and human health and livelihoods as underpinned by environmental stewardship (Fig. S30-4). AHEAD recognizes the importance of animal and human health to both conservation and development interests. Around the world, domestic and wild animals are coming into ever-more-intimate contact, and

**Figure S30-4** The AHEAD program is a landscape-level approach to addressing challenges at the interface of wildlife health, domestic animal health, human health, and livelihoods as underpinned by environmental stewardship.

without adequate scientific knowledge and planning, the consequences can be detrimental to one or both sectors. With the tools provided by the health sciences, however, conservation and development objectives have a much greater chance of being realized, particularly at the critical wildlife/livestock interface, where conservation and agricultural interests meet head-on. AHEAD efforts focus on several themes of critical importance to the future of animal agriculture, human health, and wildlife health, including zoonoses, competition over grazing and water resources, disease mitigation, local and global food security, and other potential sources of conflict related to land-use decision making in the face of resource limitations.[18-20] (To learn more about current activities, see http://www.wcs-ahead.org.)

### ONE HEALTH IN ACTION II

## *Emerging Pandemic Threats Program*

The Emerging Pandemic Threats (EPT) program of the United States Agency for International Development (USAID) emphasizes early identification of and response to dangerous pathogens in animals before they can become significant threats to human health. Using a risk-based approach, the EPT program builds on USAID's successes in disease surveillance, training, and outbreak response to focus on geographic areas where these threats are most likely to emerge. These efforts are critical to the sustainability of long-term pandemic prevention and preparedness and help develop better predictive models for identification of future viral and other biologic threats. The EPT program draws on expertise from across the animal and human health sectors to build regional, national, and local capacities for early disease detection, laboratory-based disease diagnosis, rapid disease response and containment, and risk reduction. The program accomplishes these tasks through four key subprograms: PREDICT, IDENTIFY, PREVENT, AND RESPOND. (For further information, see http://avianflu.aed.org/eptprogram/.)

The PREDICT program is building a global early-warning system to detect and reduce the impacts of emerging diseases that move between wildlife and people (Fig. S30-5). PREDICT has developed a SMART (strategic, measurable, adaptive, responsive, and targeted) surveillance method that accounts for the fact that zoonotic diseases, such as influenza and severe acute respiratory syndrome (SARS), are responsible for the majority of emerging infections in people, and that more than three quarters of these emerging zoonoses are of wildlife origin. The SMART surveillance approach is designed to detect novel diseases with pandemic potential early, giving health professionals the best opportunity to prevent emergence and spread. It also targets sentinel animal species at active human interfaces in "hot spot" regions to improve surveillance efficiency. The PREDICT team builds on a broad coalition of partners to develop the global capacity to monitor diseases at the animal-human interface and develop a risk-based approach to concentrate these efforts in surveillance, prevention, and response at the most critical points for disease emergence from wildlife.

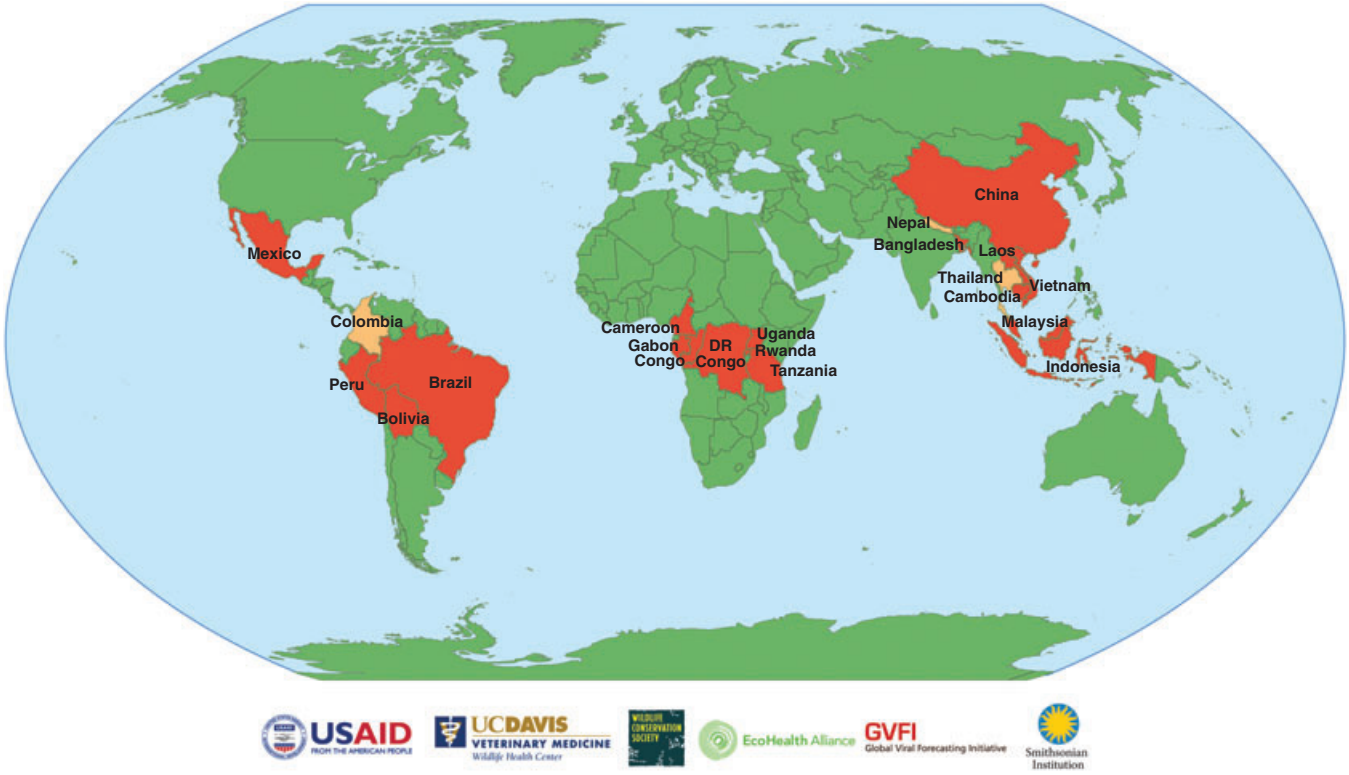


**Figure S30-5** The PREDICT program is building a global early-warning system for emerging zoonotic diseases in hot spots around the world. (From the PREDICT One Health Consortium. http://www.vetmed.ucdavis.edu/ohi/predict/publications/index.cfm.)

(See www.vetmed.ucdavis.edu/ohi/predict and http://www.vetmed.ucdavis.edu/ohi/predict/publications/index.cfm.)

The PREDICT project is working in 20 countries to:

- Assess local surveillance capacity.
- Implement targeted and adaptive wildlife disease surveillance systems.
- Develop and deliver new technologies to improve detection and response efforts close to the source.
- Use cutting-edge information management and communication tools to bring the world closer to realizing an integrated, global approach to emerging zoonotic diseases.

### ONE HEALTH IN ACTION III

### *HealthMap and Technology for Global Disease Surveillance*

A team of researchers, epidemiologists, and software developers at Children's Hospital Boston founded HealthMap in 2006. It has since been established as a global leader in utilizing online informal sources for disease outbreak monitoring and real-time surveillance of emerging public health threats. The freely available website, healthmap.org, and mobile app, Outbreaks Near Me, deliver real-time intelligence on a broad range of emerging infectious diseases for a diverse audience, including libraries, local health departments, governments, and international travelers. HealthMap brings together data sources, including online news aggregators, eyewitness reports, expert-curated discussions, and validated official reports, to achieve a unified and comprehensive view of the current global state of infectious diseases and their effect on human and animal health[21] (Fig. S30-6). Through an automated process, updating 24/7/365, the system monitors, organizes, integrates, filters, visualizes, and disseminates online information about emerging diseases in nine languages, facilitating early detection of global public health threats.

HealthMap is an innovative example of the use of technology to facilitate the integration of human and animal disease surveillance around the globe. With improved Internet capacity and accessibility worldwide, technology can contribute greatly to improving the speed and ease of communication. Mobile phone technology could play a large role in disease reporting from isolated locations. HealthMap provides a starting point for real-time information on emerging public health events. The system receives more than 1 million visitors a year, with specific use by government and other agencies (e.g., CDC, DHHS, DOD, WHO, ECDC), public health officials, and international travelers.

## IMPLEMENTATION OF ONE HEALTH FRAMEWORK

### COMMUNICATION

The development of communication routes will also be essential to One Health.[22,23] Traditionally, communication among public health, veterinary, and environmental authorities has been poor.[2] Joint surveillance will be a necessity as well, and new web-based strategies offer innovative solutions, such as HealthMap (see One Health in Action III), and

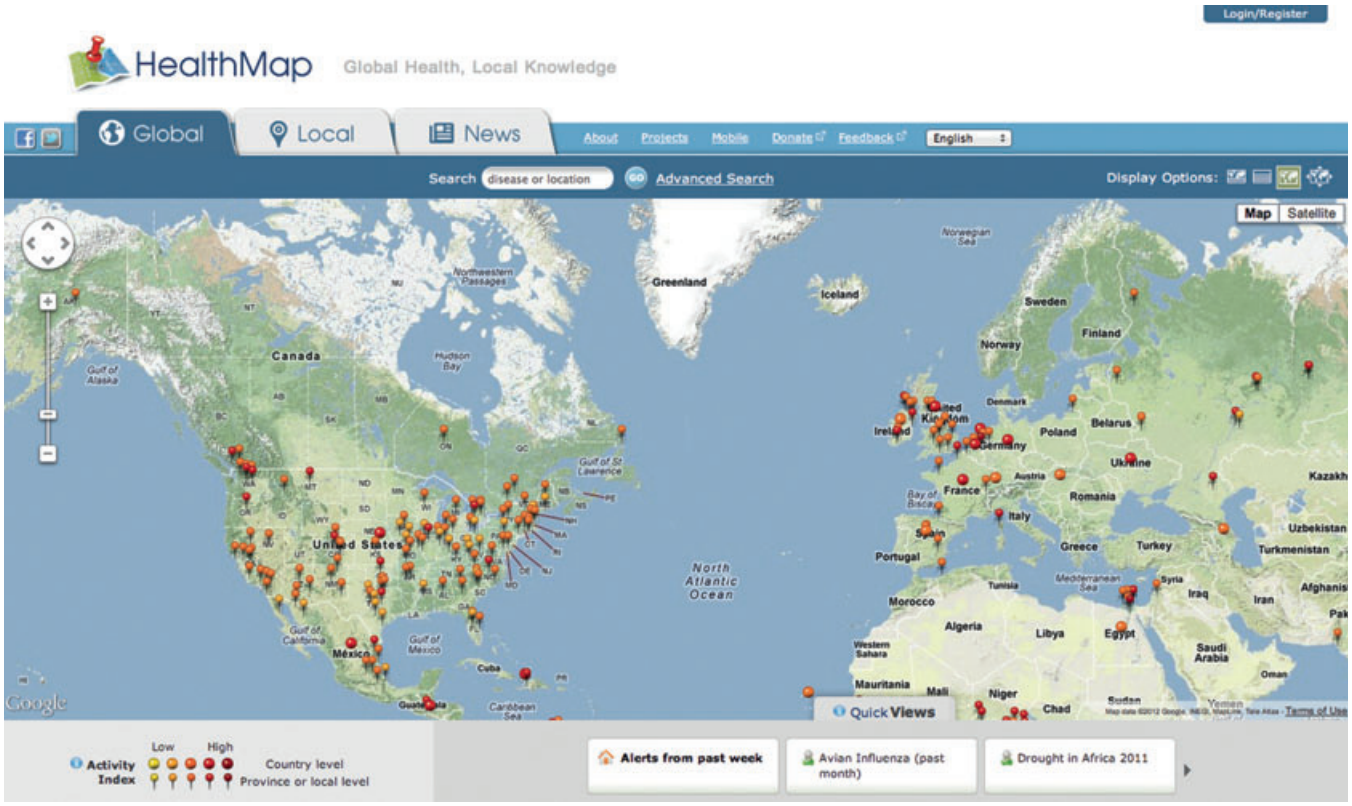


**Figure S30-6** HealthMap filters, verifies, and curates animal and human disease outbreak information, placing it into a global map for visualization. (Modified from http://healthmap.org/about/.)

the Program for Monitoring Emerging Diseases (ProMed mail), a reporting system "dedicated to rapid global dissemination of information on outbreaks of infectious diseases and acute exposures to toxins that affect human health, including those in animals and in plants grown for food or animal feed" (http://www.promedmail.org/aboutus/).

## INSTITUTIONAL

It will be important to engage ministries, agencies, institutions, and private industry across sectors, which will require new models of institutional cooperation. This cooperation requires an improved understanding of institutional missions, capacities, responsibilities, and leadership to maximize collaboration and minimize duplication.[22] Recommendations include building cooperation around tangible and immediate issues such as surveillance, creating a clear operational process with identified roles, and sharing staff and facilities from different organizations.[23] Existing examples of interagency collaborative efforts (e.g., among WHO, FAO, and OIE) will serve as important structural models.

## TECHNICAL/EDUCATIONAL

The development of One Health professional capacity will be essential for implementing this approach and will require new skill sets.[22,23] Promoting this capacity requires technical training for existing professionals and educational training for future professionals. Ongoing training could occur in the form of short-term One Health workshops, joint working groups across institutions, and participation in international conferences where One Health networks can be strengthened.[24] The collaborative groundwork for One Health can be developed through existing national and international resources. Training, networking, and problem-based learning in a professional career can build the necessary interdisciplinary foundations. International partnerships can also be achieved by reading and publishing in journals with an international research focus. For example, *EcoHealth* is dedicated to integrating knowledge between the ecological and health sciences and reaches a highly interdisciplinary audience. By exposing more practitioners to relevant information from each discipline, a larger cadre of professionals would become more aware of why, how, and when to access experts and resources from another field in response to a particular health issue.[24] It will also be important to educate about liability risk for professionals acting in an unfamiliar field.

There is a great opportunity to begin building One Health capacity early in the educational process.[24-26] Universities have increasingly engaged in seeking global health solutions,[27] but their efforts often lack interdisciplinary opportunities for students. This may stem from the traditional anthropocentrism of medical education. Initially, One Health training could be incorporated into standard curricula.[24] For example, less than 3% of the total veterinary curriculum in the United States is devoted to public health issues,[28] resulting in fewer than 2% of current veterinarians working in public health.[29] Similarly, medical training maintains a strict focus on human health. Neither discipline receives training in basic environmental science, despite its

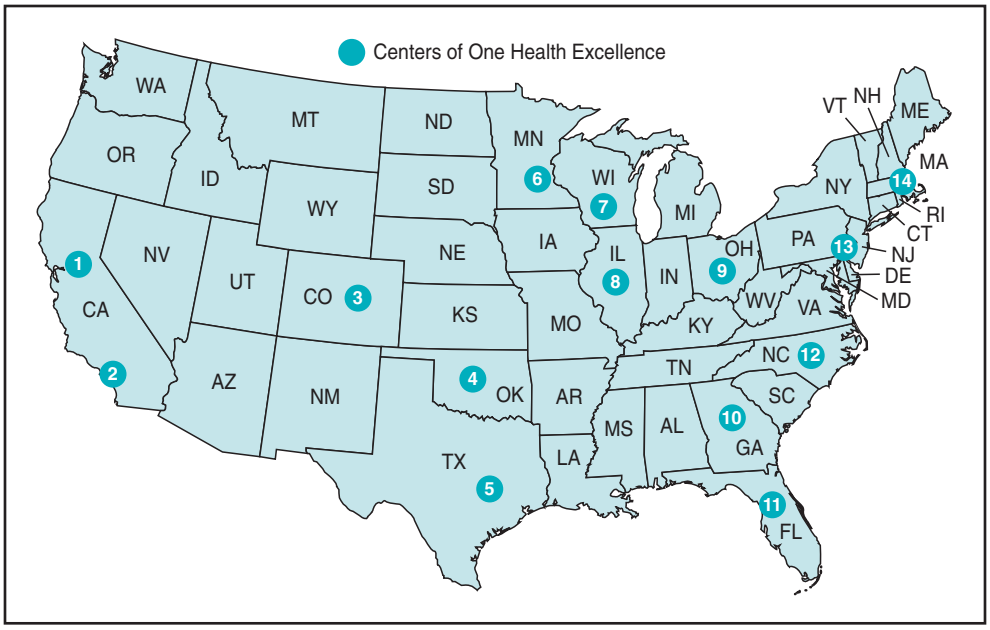


**Figure S30-7 Potential centers of One Health excellence (COHE) in the contiguous United States.** By analyzing the proximity of academic centers for veterinary medicine (Vet), medicine (Med), environmental science (Env), and public health (PH), we identified those hot spots of high potential for One Health collaboration. "All" indicates co-location of all four disciplines at one institution; subscripts indicate multiple programs in the COHE area.

1. All: University of California (UC) Davis.
2. Vet: Western University of Health Sciences; $Med_3$: UC Irvine (UCI), UC Los Angeles (UCLA), University of Southern California (USC); $Env_4$: UC Irvine, UC Riverside, UCLA, University of Redlands; $PH_5$: California State University (CSU) Northridge, CSU Long Beach, UCLA, UCI, USC.
3. Vet: Colorado State University (CSU); Med: University of Colorado (UC) Denver; $Env_3$: CSU, UC Boulder, UC Denver; $PH_2$: UC Denver, University of Northern Colorado; Govt Agency: US Geological Society National Wildlife Health Center.
4. Vet: Oklahoma State University (OSU); Med: University of Oklahoma (UO); $Env_2$: OSU, UO; PH: UO.
5. All: Texas A&M University.
6. All: University of Minnesota.
7. All: University of Wisconsin–Madison.
8. All: University of Illinois–Urbana-Champaign.
9. All: Ohio State University.
10. Vet: University of Georgia (UGA); $Med_2$: Emory University (EU), Morehouse School of Medicine; $Env_3$: EU, UGA, Georgia Institute of Technology; $PH_4$: EU, UGA, Georgia State University; Govt Agency: Centers for Disease Control and Prevention.
11. All: University of Florida.
12. Vet: North Carolina State University (NCSU); $Med_2$: Duke University (DU), University of North Carolina (UNC), $Env_3$: DU, UNC, NCSU; PH: UNC.
13. Vet: University of Pennsylvania (UP); $Med_4$: Temple University, Thomas Jefferson University, UP, Drexel University (DU); $Env_4$: University of Delaware, DU, UP, Princeton University; PH: UP.
14. Vet: Tufts University (TU); $Med_5$: University of Massachusetts (UM) Worcester, Boston University (BU), Harvard University (HU), TU, Brown University; $Env_5$: Brown University, BU, TU, UM Boston, UM Amherst; $PH_4$: BU, Harvard University, TU, UM Amherst.

*Note:* Addition of a COHE in Kansas should also be included: Vet: Kansas State University (KSU); Med: University of Kansas; Env: KSU; PH: KSU. Modified from Barrett MA, Bouley TA, Stoertz AH, et al: Integrating a One Health approach in education to address global health and sustainability challenges, *Frontiers Ecol Environ* 9(4), 2010.

proven relevance to each field and to global health.[30] Universities could also integrate veterinary, medical, and environmental science students through common course work, web courses, and distance learning.[24] Courses that would enable this discourse include global health, public health, environmental health, ecotoxicology, pathology, microbiology, and emerging infectious disease.

Simple changes in curricula or interdisciplinary student diversity may not be enough to truly foster long-lasting, interdisciplinary thinking. Summer One Health workshops can bring together students with equal disciplinary representation and include both lecture and problem-based learning (e.g., Envirovet: http://vetmed.illinois.edu/envirovet). An expansion of the global health case competition model, as already conducted by several universities, would also be effective. In a case competition, small, interdisciplinary groups confront One Health issues, with the aim of developing collaborative solutions. Students should also receive leadership and communication training.

Given the current limited funding landscape, academic institutions may not have the resources to create new institutes or centers dedicated to One Health. Instead, One Health collaborations could build on existing academic resources, programs, departments, and relevant schools close to one another. A recent study assessed the spatial proximity of such programs across the United States to identify areas of potential One Health collaboration.[24] Co-located universities with programs in medicine, veterinary medicine, public health, and environmental science within a 1-hour drive of each other were identified (Fig. S30-7). This is not an exhaustive

list but does present 14 areas with high One Health potential for collaboration.

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