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Review

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Optimization of human, animal, and environmental health by using the One Health approach

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Emerging diseases are increasing burdens on public health, negatively affecting the world economy, causing extinction of species, and disrupting ecological integrity. One Health recognizes that human, domestic animal, and wildlife health are interconnected within ecosystem health and provides a framework for the development of multidisciplinary solutions to global health challenges. To date, most health-promoting interventions have focused largely on single-sector outcomes. For example, risk for transmission of zoonotic pathogens from bush-meat hunting is primarily focused on human hygiene and personal protection. However, bush-meat hunting is a complex issue promoting the need for holistic strategies to reduce transmission of zoonotic disease while addressing food security and wildlife conservation issues. Temporal and spatial separation of humans and wildlife, risk communication, and other preventative strategies should allow wildlife and humans to co-exist. Upstream surveillance, vaccination, and other tools to prevent pathogen spillover are also needed. Clear multi-sector outcomes should be defined, and a systems-based approach is needed to develop interventions that reduce risks and balance the needs of humans, wildlife, and the environment. The ultimate goal is long-term action to reduce forces driving emerging diseases and provide interdisciplinary scientific approaches to management of risks, thereby achieving optimal outcomes for human, animal, and environmental health.

Keywords: One Health, avian influenza, disease prevention, emerging infectious diseases, global health

Introduction: Why One Health?

Emerging infectious diseases, defined as novel or known infectious diseases increasing in incidence within a specific location or population, and environmental contaminants pose global and profound threats to human, animal, and environmental health [17,32,39]. The rise of emerging infectious diseases demonstrates the dynamic relationship among pathogens, hosts, and their environment [20,32,39]. Over sixty percent of emerging infectious diseases are zoonotic, and over seventy percent of those zoonoses have a wildlife origin [20], including highly pathogenic avian influenza (HPAI), sylvatic plague, Lyme disease, anthrax, and severe acute respiratory syndrome (SARS). These diseases increase burdens on public health systems, negatively impact the world economy, cause declines and extinctions of animal species, and increase loss of ecological integrity [8,23]. The potential global impact of a wildlife-associated pathogen on human health is exemplified by the over 35 million people currently infected with human immunodeficiency virus (HIV), which is reported to have originated from a simian (primate) virus [13]. Likewise, negative effects of emerging and resurging diseases on agriculture, food safety and security, wildlife health, and human health in Southeast Asia have resulted from outbreaks of HPAI [16,29,40]. There are also several newly described pathogens and diseases that have resulted in wildlife population declines and global extinctions. *Batrachochytrium dendrobatidis*, a cutaneous fungal infection of amphibians, is linked to global declines of amphibian populations [22], and *Pseudogymnoascus destructans*, the etiologic agent of white-nose syndrome, has caused precipitous declines in the abundance of North American hibernating bat species [3]. Such large-scale losses of animal species and biodiversity subsequently jeopardize the ecosystems on which all life depends [7,18]. Of particular concern are novel emerging infectious diseases of wildlife origin as they are difficult to anticipate, devastating to wildlife populations, challenging to manage, and have the potential to have ecological ripple effects. Emerging diseases and

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pathogens of wildlife origin are increasing globally at alarming rates, in both incidence and by geographic location, which can be largely attributed to the driving forces of globalization, an increasing human population, and climate change [8,20,23,48].

Globalization, including the rising amounts of international human travel and trade in animal- and plant-based products and other goods, potentiates the spread of pathogens [21,23,24,35,49,51]. Emerging infectious diseases are also driven by socio-economic, environmental, and ecological factors, including ecological disruption, microbial adaptation, and lack of preventative measures [6,8]. For example, outbreaks of HPAI in Southeast Asia present ongoing challenges to biosecurity and food safety related to trade, transport, and marketing of poultry within and between countries [11,46]. The growing human population and the ensuing urban development increase interactions among people, domestic animals, and wildlife, further escalating the risk for transmitting pathogens and initiating novel disease outbreaks [5,14,23,50]. Climate change can also facilitate the movement of pathogens into new geographic regions [34,42]. Additionally, climate change is altering insect population dynamics and increasing the potential for spread of vector-borne diseases, which constitute twenty to thirty percent of all emerging infectious diseases [15,20,36].

As a demonstration of an interconnected system, bats contribute up to 50 billion USD annually to the United States of America (US) agricultural economy through their part in insect control [4]. However, the emergence of white-nose syndrome has resulted in the death of over 6 million bats in North America resulting in a marked decrease in insect control [3]. Additionally, while bats are critical components of world ecosystems, they are also potential reservoirs of zoonotic viruses, including rabies, Marburg virus, and Nipah virus [27]. In today's age of dynamic changes in the emergence of infectious diseases associated with increasing interactions among humans, domestic animals, and wildlife, the need to consider these interactions fully becomes crucial for effective management that balances the needs of humans, animals, and the environment.

Such issues are not limited to infectious diseases. For example, while it has long been known that human exposure to unsafe levels of methylmercury is predominantly through dietary consumption of contaminated fish and shellfish, recent technological advances in high-resolution mass spectroscopy now provide a means to "fingerprint" the contributing mercury and determine its source [26]. For example, many locations are impacted by both point-source releases as well as nearly ubiquitous atmospheric fallout of mercury. This new fingerprinting capability has extended the capacity to determine which mercury sources contribute to fish, wildlife, and human exposures, thereby informing environmental decision makers of the most effective means to reduce such exposures.

What Is One Health?

The concept of One Health, defined as the collaborative effort of multiple disciplines—working locally, nationally, and globally—to attain optimal health for people, animals, and the environment, has been receiving growing recognition (One Health Commission, USA; Fig. 1). One Health acknowledges that human, domestic animal, and wildlife health are interconnected within the context of ecosystem health and provides a useful conceptual framework for the development of solutions to global health challenges. To date, most health-promoting interventions have focused largely on single-sector outcomes. By using the One Health concept as a framework, disease management and regulatory strategies can optimize outcomes for humans, animals, and the environment. For example, risk for transmission of zoonotic pathogens from wildlife to bush-meat hunters and other consumers of bush-meat is regarded as a public health issue, and current interventions focus primarily on educating bush-meat hunters about hygiene and personal protection (United States Agency for International Development [USAID], USA). However, bush-meat hunting is a complex issue with environmental and food security consequences if conducted unsustainably; thus, the need to support holistic strategies to reduce transmission of zoonotic disease while simultaneously ensuring food security and safeguarding wildlife populations.

Opportunities for a One Health Approach

Emerging infectious diseases have non-random global patterns of emergence [20], and development of the ability to appropriately predict, detect, and respond to emerging infectious diseases is crucial in preventing the spread of such diseases. Opportunities to implement a One Health approach are enhanced by the availability of new technologies and methodologies, including surveillance tools, diagnostics, and vaccines that have been developed through applied research

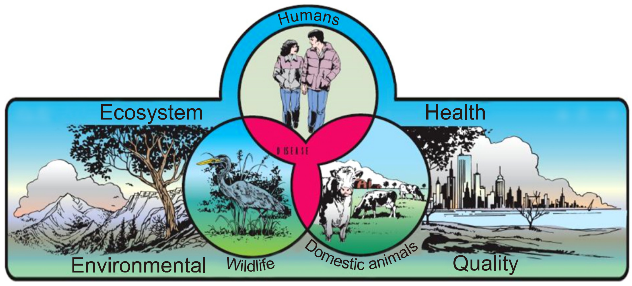

Fig. 1. Diagram illustrating the concept of One Health; that is, the connection of human, domestic animal, and wildlife health within the context of ecosystem health. Figure designed by John M. Evans, USGS.

[32]. For example, the development of new laboratory technologies and computational methods has facilitated major advances in our ability to detect and characterize emerging contaminants and pathogens and to define disease risks. Specifically, advances in molecular biology have opened new avenues for the identification and detection of pathogens [47], and spatially referenced database applications allow for risk assessments that can assist in spatial and temporal targeted disease surveillance in accordance with anticipated disease threats. However, just as health interventions are often single-sector focused, disease surveillance systems may be equally limited. There are instances of major threats to human or domestic animal health that were unrecognized due to the lack of integration of environmental, wildlife, domestic animal, and public heath surveillance data [43]. For example, there were delays in recognizing that human cases of encephalitis and concurrent mortalities of crows in New York, United States in 1999 shared the West Nile virus as a common etiology due to the absence of an established communication protocol between the public health and wildlife health sectors [31]. Additionally, there is often insufficient surveillance in wildlife populations, thereby delaying the identification of and response to a disease event, consequently resulting in increased negative effects on wildlife and domestic animals. For example, a recent outbreak of Peste de Petits Ruminants in saiga antelope (*Saiga tatarica mongolica*) from Mongolia went unrecognized for several months, resulting in loss of approximately 50% of the population (Food and Agriculture Organization of the United Nations [FAO], Italy). Surveillance in wildlife populations not only can protect wildlife from disease but also can provide early detection and rapid responses to domestic animal and public health threats, as a consequence of upstream surveillance (Fig. 2).

In addition, epidemiological studies to determine disease

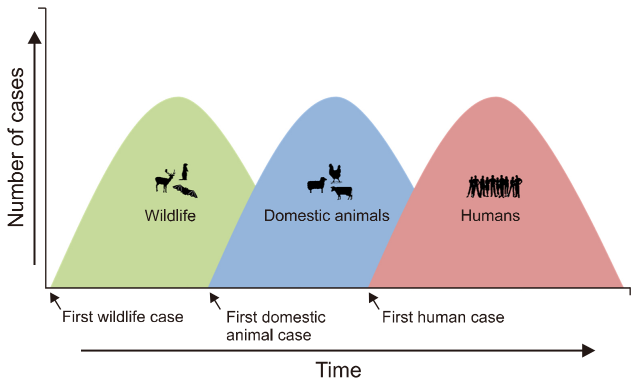

Fig. 2. Hypothetical example of how detection of pathogens or diseases in wildlife prior to the detection of cases in domestic animals and humans can provide an early detection, rapid response system for the agriculture and public health sectors.

causation allow the development of interventions based on temporal and spatial separation of humans, domestic animals, and wildlife, as well as other preventive measures. Risk communication to modify human behaviors, along with other disease management strategies, are also needed to prevent disease transmission and allow wildlife and humans to co-exist in the same environment [14]. Finally, development of specific disease-management tools or interventions should follow a One Health approach. For example, oral vaccination of wildlife for rabies control has been important in minimizing exposure of domestic animals and humans to the deadly virus [37,45]. In another developing example, an orally ingestible vaccine is being used to prevent sylvatic plague in prairie dogs and sympatric endangered black-footed ferrets to conserve both wildlife populations and protect human health [1]. By implementing a One Health approach, such holistic strategies should become more common in promoting global health and ecological sustainability.

One Health in Action

The US government response to HPAI in wild and domestic birds is an example of One Health in action. In the late fall of 2014, the US experienced an unprecedented introduction of a Eurasian strain of the HPAI virus [25]. This virus, termed HPAI H5N8, was likely introduced by wild waterfowl during their normal migratory movements between Asia and North America. Once introduced, the HPAI H5N8 virus quickly spread along the Pacific Flyway of the US, and began mixing with the low pathogenic, native North American avian influenza viruses, resulting in the creation of two novel HPAI viruses. One of these novel viruses, termed HPAI H5N2, spread to the Central and Mississippi Flyways in the US Midwest in winter and spring of 2015. Collectively, these HPAI viruses were responsible for the costliest animal disease emergency event ever documented in the US, resulting in a loss of over four billion USD to the American agriculture industry and the US economy [12,41].

In response to the HPAI virus introduction, the Interagency Steering Committee for Avian Influenza Surveillance in Wild Migratory Birds (Interagency Steering Committee), comprised of state and federal scientists from the US Departments of Agriculture, the Interior, and Health and Human Services, and state natural resources agencies, coordinated state and federal scientists in the development and implementation of an enhanced surveillance system for the Pacific Flyway [2]. By the end of January 2015, only six weeks after the initial HPAI detection, over 4,000 wild birds were sampled and tested, effectively documenting the role of specific species of wild ducks as reservoirs for the viruses, the particular sensitivity to infection of raptor species resulting in morbidity and mortality, the distribution of the HPAI H5N8 virus throughout the Pacific

Flyway with limited spread of the HPAI H5N2 form, and, by using genetic sequence analysis, confirming that the viruses had not yet developed the capacity to infect mammals, including humans.

Unfortunately, by March and April of 2015, new infection foci were established in the US Midwest. Once again, federal and state wildlife disease experts were mobilized to investigate the role wildlife species were playing in these new outbreaks and to assist in determining how the viruses might be moving among farms and the environment. Additionally, the Interagency Steering Committee identified a working group of federal and state wildlife and agricultural ecologists, veterinarians, biologists, epidemiologists, and statisticians, which was assigned to develop a National Surveillance Plan that would identify the distribution of the HPAI viruses in wild birds throughout the US [19]. This group relied heavily on knowledge gained from the previous surveillance program as well as using information from ongoing research into avian influenza in wild birds.

In July 2015, the Interagency Steering Committee led the implementation of the US National Surveillance Plan for Highly Pathogenic Avian Influenzas in Wild Birds [19]. Through that plan, over 77,000 wild birds were successfully tested for HPAI by January 2017, thereby documenting a persistent circulation of HPAI H5N2. The success of this program indicates how interagency collaborations can effectively and efficiently protect US agriculture, natural resources, and human health and safety. For example, the wild bird surveillance program has effectively provided early warnings to the poultry industry, agricultural officials, wildlife agencies, conservation programs, wildlife rehabilitators, zoos, and public health officials regarding the potential introduction and emergence of HPAI viruses. The program has also improved on-farm biosecurity measures by providing enhanced biosecurity recommendations to the poultry industry [44]. These recommendations were primarily developed through recognition of the risks of creating habitat for wildlife near poultry production facilities that would inadvertently provide food, water, and shelter to wild birds and mammals. The recommendations also sought to modify and enhance management practices on farms to prevent transmission by the movement of people, feed, equipment, and waste products.

The US surveillance program for HPAI in wild birds is also seen as a model of One Health collaboration through its communication and outreach efforts to stakeholders and the public. The Interagency Steering Committee and its member agencies have produced numerous fact sheets, frequently asked questions, webinars, presentations, and web pages to keep scientists, policy makers, industry, and the public up-to-date on the global status of avian influenza and the US HPAI surveillance program, on how producers can minimize the risk of transmission to poultry, and on how hunters and poultry workers can minimize the risk of acquiring diseases from handling birds.

The One Health approach toward detecting and managing avian influenzas in the US has been successful because of several factors, the primary one being effective collaboration. Through identification of a clear purpose and vision, establishment of a governance structure, and by setting achievable goals, the Interagency Steering Committee was able to rapidly develop national surveillance strategies and plans. This could not have been possible without policy-level support, which facilitated the commitment of participating agencies to work together on avian influenzas over the last 14 years [9]. Policy-level support has been identified as a key component of successful collaborations in One Health programs [6,10,30,33]. Successful collaborations are also fostered through active communication among partners, information exchange within and across agencies, policy makers, and the public, as well as with the participation of stakeholders. For example, the public is encouraged to report sick and dead birds to wildlife officials, most apparently healthy wild bird samples are obtained from hunter-harvested birds, and there is active surveillance on farms during outbreaks.

Another, and perhaps most important, factor in the success of the One Health approach in detecting and managing avian influenzas in the US is the presence of advocates who were dedicated and committed to the cause, even when that cause was not their primary job focus. In this case, it is the members of the Interagency Steering Committee, many of who have been committee participants for over 10 years. Similarly, a review of several interagency One Health projects revealed that certain common factors, including group and individual leadership skills, were essential to the success of the projects [38]. However, while progress has been made toward integration of disciplines, some segregation remains, as was illustrated by a recent study that showed that sectors continue to differ in the systems studied, questions asked, and methods employed [28].

Conclusions

The One Health concept is important in the development of interventions and actions that optimize outcomes for human, animal, and environmental health. The growing challenges presented by globalization, climate change, environmental contamination, human population growth, agricultural and urban development, and degraded ecological integrity pose substantial risks to global health, food security, and ecological sustainability, especially through the spread of emerging and zoonotic diseases. With the multitude of influencing factors, not only will occurrences of emerging infectious diseases persist, but the rate at which emerging infectious diseases are observed will also increase [6]. Improved regulatory frameworks and holistic management strategies are needed to mitigate these emerging threats. To guide this response, clear multi-sector outcomes need to be defined. Understanding the epidemiology of relevant diseases, the unique challenges presented by each disease, and the current strategies used in the management of applicable diseases is needed to undertake properly informed decision-making and to support a One Health, systems-based approach to the development of interventions that will reduce risks and balance needs of humans, animals, and the environment. The ultimate goal will be to focus on long-term action directed at reducing the factors driving emerging diseases and contaminants and to provide interdisciplinary scientific approaches to manage environmental contaminants and emerging, high-consequence disease risks in order to achieve optimal outcomes for human, animal, and environmental health.

Conflict of Interest

The authors declare no conflicts of interest.

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