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Forum

Has the Time Come for Big Science in Wildlife Health?

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Abstract: The consequences of wildlife emerging diseases are global and profound with increased burden on the public health system, negative impacts on the global economy, declines and extinctions of wildlife species, and subsequent loss of ecological integrity. Examples of health threats to wildlife include *Batrachochytrium dendrobatidis*, which causes a cutaneous fungal infection of amphibians and is linked to declines of amphibians globally; and the recently discovered *Pseudogymnoascus* (*Geomyces) destructans*, the etiologic agent of white nose syndrome which has caused precipitous declines of North American bat species. Of particular concern are the novel pathogens that have emerged as they are particularly devastating and challenging to manage. A big science approach to wildlife health research is needed if we are to make significant and enduring progress in managing these diseases. The advent of new analytical models and bench assays will provide us with the mathematical and molecular tools to identify and anticipate threats to wildlife, and understand the ecology and epidemiology of these diseases. Specifically, new molecular diagnostic techniques have opened up avenues for pathogen discovery, and the application of spatially referenced databases allows for risk assessments that can assist in targeting surveillance. Long-term, systematic collection of data for wildlife health and integration with other datasets is also essential. Multidisciplinary research programs should be expanded to increase our understanding of the drivers of emerging diseases and allow for the development of better disease prevention and management tools, such as vaccines. Finally, we need to create a National Fish and Wildlife Health Network that provides the operational framework (governance, policies, procedures, etc.) by which entities with a stake in wildlife health cooperate and collaborate to achieve optimal outcomes for human, animal, and ecosystem health.

Keywords: emerging diseases, wildlife health, disease prediction, disease management, big science, One Health

Fifty years ago, infectious diseases were rarely considered threats to wildlife populations, and the study of wildlife diseases was largely a neglected endeavor. Leap forward to today, and there is now a large body of evidence that illustrates the role of pathogens and pollutants in the decline of wildlife populations. Furthermore, there is increasing evidence of the subsequent impacts on human and ecosystem health (for examples, see LoGiudice et al. 2003 and Boyles et al. 2011). In recent times there has been an unprecedented increase in the number of emerging infectious diseases, of which a majority is of wildlife origin (Taylor et al. 2001). Examples of drivers of these diseases include climate and landscape changes, human demographic and behavior changes, global travel and trade, microbial adaptation, and lack of appropriate infrastructure for wildlife disease control and prevention (Daszak

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et al. 2001). The consequences of these emerging diseases are global and profound with increased burden on the public health system, negative impacts on the global economy, declines and extinctions of wildlife species, and subsequent loss of ecosystem integrity. Examples of health threats to biodiversity include the "spill-over" of human diseases to great ape populations (Köndgen et al. 2008), the near-extirpation of the black-footed ferret from canine distemper and sylvatic plague (for a review see Abbott et al. 2012), and threats to Hawaiian forest birds from introduced pathogens such as avian malaria and avian pox (van Riper et al. 1986, 2002). Contaminants also threaten the persistence of wildlife species; for example, lead continues to be an impediment to the recovery of the California condor (Finkelstein et al. 2012), and vulture populations in Asia have declined dramatically as a result of the consumption of animal carcasses containing diclofenac acid, a commonly used non-steroidal anti-inflammatory drug (Oaks et al. 2004). Furthermore, some diseases such as chronic wasting disease in elk and deer represent a significant threat from the adverse economic impact of these diseases on wildlife management agencies' abilities to manage and conserve wildlife due to negative public perception of infected wildlife (Almberg et al. 2011; Zimmer et al. 2011). There are also several newly discovered pathogens or diseases that have resulted in population declines, and global extinctions of several species. Examples include *Batrachochytrium dendrobatidis*, which causes a cutaneous fungal infection of amphibians and is linked to declines of amphibians globally (Kriger and Hero 2009); recently discovered *Pseudogymnoascus* (*Geomyces) destructans*, the etiologic agent of white nose syndrome which has caused precipitous declines of North American bat species (Blehert et al. 2011); and Tasmanian Devil facial tumor disease, an infectious cancer threatening the Tasmanian devil with extinction (McCallum and Jones 2006). Of increasing concern are these novel pathogens that have emerged as they are hard to anticipate, particularly devastating to wildlife populations, challenging to manage, and may result in ecological ripple effects that are difficult to predict.

Emerging diseases research has understandably focused on zoonotic diseases (for example, Goa et al. 1999) and there is now a need for a focus on those diseases that threaten biodiversity and ecosystem integrity. One potential reason for this lack of attention is the historically poor success rate of attempts to manage diseases in wildlife populations. A review of the sparse literature on wildlife disease management reveals a sense of defeatism with very few examples of success (Wobeser 2006). However, human societies have made significant and enduring progress in unraveling some of our most vexing and intractable challenges through "big science." The term big science was coined by the physicist Alvin Weinberg in 1961 to describe the large-scale research in physics that had developed during and after World War II (Weinberg 1961). One of the best known big science projects includes the high energy physics facility at CERN, at which the Large Hadron Collider (www.lhc.ac.uk) was recently used to discover the Higgs boson, or the "God Particle"; the basic building block of the universe. Big science has more recently been applied to the biological sciences, with the Human Genome Project (http://web.ornl.gov/sci/techresources/Human_Genome/index.shtml) presented as one of the first large-scale "big biology" research projects and is recognized to have potentially enormous medical benefits. Big science is characterized by the development and use of new or large-scale technologies; sustained funding from governments or international organizations; new infrastructures; and the science is conducted by multidisciplinary teams of scientists and technicians (Vermeulen 2013). In addition, the purpose of the research is to address a societal need or demand and is often a combination of fundamental and applied research.

Furthermore, there has been some intellectual movement in the direction of a collective definition of health. In particular, the One Health movement (see: www.onehealthinitiative.com) recognizes that human, domestic animal, and wildlife health are all interconnected within the context of ecosystem or environmental health. It requires the collaborative effort of multiple disciplines—working locally, nationally, and globally—to attain optimal health for people, animals, and our environment. While not a big science project per se, it does provide a useful theoretical model which can be used to develop solutions.

A big science, One Health approach to wildlife disease surveillance, research and partnerships is needed. Early detection of emerging disease threats will remain an important component of an overall strategy. Ensuring there is the field network and state-of-the-art laboratory capacity to detect and identify novel emerging pathogens is essential, and the application of new molecular diagnostic technologies such as next generation sequencing has opened up avenues for pathogen discovery previously unheard of (Relman 1998; Wang et al. 2003). We have established Earth (Landsat: landsat.usgs.gov) and climate monitoring systems (NOAA: www.nesdis.noaa.gov) that provide continuous imagery, atmospheric measurements, and climatic data, and we have global public health surveillance systems for human diseases (WHO: http://www.who.int/research/en/), yet we lack the same ongoing, systematic collection of data for wildlife health. Integration of data from such a long-term data system with data from a variety of sources including human and animal health data, climatic, ecologic, hydrologic, geologic and socio-economic data, among other sources, will allow a deeper understanding of the environmental drivers and the generation of predictive models of "hot spots" of disease emergence (Jones et al. 2008). This will ultimately allow for the targeting of resources to geographic areas and populations at greater risk and the prevention of disease emergence and spread. The development of new analytical models will also provide us with the mathematical tools to identify and anticipate threats to wildlife, understand the distribution, dynamics, and impacts of disease, and ultimately provide better information for guiding management decisions. Recognizing that not all diseases will be predicted and prevented, the biggest deficiency is a suite of tools that can be mobilized to manage diseases in wildlife populations. The current methods such as culling are crude, unpopular, and generally ineffective. Vaccines are probably the primary, cost-effective public health, and veterinary intervention available and have been used widely to save millions of lives, and reduce economic losses. Very few vaccines are available for use in free-ranging wildlife populations due to the challenges of delivery; however, the oral rabies vaccine has reduced the prevalence of rabies infection in wildlife, and was used to successfully eradicate fox rabies from Western Europe (Brochier et al. 1991). Further research in the development of safe and effective vaccines that can be mass delivered to wildlife populations, as is being done to develop a sylvatic plague vaccine for prairie dogs (Abbott et al. 2012), would allow for this technique to become mainstream in wildlife health. Thinking outside the box to unleash new science and technologies for wildlife disease control would result in new, innovative techniques ranging from improvements in biosecurity to prevent spillover of diseases into wildlife populations to ways to manipulate vectors or pathogens through biological control agents, to name two. The rapid advances in medical sciences and technology have saved countless human lives, and could equally be applied to conserving wildlife populations.

Finally, we need the robust partnerships to address these pressing issues of mutual concern. While the One Health concept recognizes the interconnectedness of human, animal, wildlife, and ecosystem health, the infrastructure to respond to wildlife health emergencies is lacking. Until we have the operational framework (the network of partners, with appropriate governance, policies, procedures, etc.) by which agencies and institutions with a stake in wildlife health cooperate and collaborate to achieve optimal outcomes for human, animal, and ecosystem health, the third leg of the One Health stool [the three legs being (1) human, (2) domestic animal, and (3) wildlife health] will always be missing. In one sense this is a leadership challenge. Interdisciplinary teams are more likely to be successful when there is a unified task and shared goals and values, and when personal relationships are developed from a foundation of trust and respect (Anholt et al. 2012). What are the common core values of One Health, and do we have the individual leadership skills, such as an ability to think beyond the boundaries of one's own agency or institution to make One Health successful?

The wildlife health research community has done an excellent job in identifying and defining disease threats to wildlife, yet we have largely stalled when it comes to the development of disease prevention tools and management options. Solutions are within our grasp if we think big, boldly, and creatively. Impoverishment of our biodiversity is no longer solely a wildlife conservation issue, and the consequences for human societies and ecosystem integrity are increasingly recognized. Big science, through sustained investments in new technology and science, and the development of the necessary physical infrastructures and operational networks will help make the transformations needed to address this global issue. This is a shared leadership responsibility we all must willingly accept and thinking big science will help us make that leap into the future.

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