Global Factors Driving Emerging Infectious Diseases

Impact on Wildlife Populations

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The extinction of species across the globe is accelerating directly or indirectly from human activities. Biological impoverishment, habitat fragmentation, climate change, increasing toxification, and the rapid global movement of people and other living organisms have worked synergistically to diminish ecosystem function. This has resulted in unprecedented levels of disease emergence driven by human-induced environmental degradation, which poses a threat to the survival and health of biodiversity. What is often overlooked in the discussion of the health consequences to humans is that critically endangered wildlife species are at grave risk of extinction by disease outbreaks. As habitat becomes more compressed and with migration routes cut off, gene pools of small species are stranded in isolated habitat fragments. Species now are vulnerable to encroachment, malnutrition, environmental pollutants, and epidemics from domestic animals and humans. Furthermore, the continuous degradation of ecosystems is leading to increased stress, immunosuppression, and greater susceptibility to disease. Disease can be catastrophic to a diminished stressed population, becoming in some instances the leading factor of local, regional, and global extinctions. The strategies of the new field of conservation medicine include long-term monitoring, health assessment, and interventions to protect species at risk. We particularly must minimize the threat of any potentially catastrophic disease outbreaks resulting from anthropogenic changes to the environment. Current and future diagnostic molecular techniques offer new opportunities to identify tools for the management and possible treatment of diseases in imperiled species.

Key words: **conservation medicine; ecological health; emerging infectious disease; extinction; globalization; habitat fragmentation; sentinel species; wildlife**

Disease and Environmental Change

The extinction of species across the globe is accelerating directly or indirectly from human activities. Biological impoverishment, habitat fragmentation, climate change, global toxification, and the human ecological footprint have worked synergistically to diminish ecosystem function. This has resulted in unprecedented levels of disease emergence.[1,2]

Deforestation, human settlement sprawl, industrial development, road construction, large water control projects (such as dams, canals, irrigation systems, and reservoirs), and climate change have all been accompanied by global increases in morbidity and mortality from emergent and re-emergent infectious diseases.[3]

Since 1976 the World Health Organization has recorded over 40 emerging and re-emerging infectious diseases[4]; many of these, such as malaria and dengue fever, are the direct result of landscape changes. The rising

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incidence of Lyme disease, linked to habitat fragmentation, and malaria, linked to deforestation in the Amazon, are some examples.[5,6]

In Malaysia, intensive management of pig production in farms located in fruit bat habitat led to the spillover of Nipah virus into pigs and then humans. Recent research has demonstrated that flying foxes are natural reservoirs of this paramyxovirus and other viral agents, including an Australian rhabdovirus and Hendra virus.[1,7]

The severe acute respiratory syndrome (SARS) outbreak in Asia showed a similar linkage to bush meat harvesting. The global rate of tropical deforestation continues at staggering levels with nearly 2–3% of forest habitats lost per year. In parallel to this ecological destruction is an exponential growth in human and wildlife conflict, yielding novel exposure to new diseases for all species concerned.[1,8]

Pathogen Pollution—the Infectious Element of Invasive Species

Wildlife populations are adversely affected by habitat loss, fragmentation, and pollution. But recent research points to an overlooked phenomenon that is causing species extinctions globally—pathogen pollution, the human introduction of diseases into new regions.[9] One striking example is the global decline of amphibian populations. Since the 1970s, amphibians have been disappearing from pristine areas: national parks in the United States and Canadian Rockies, wilderness sites in Costa Rica and Panama, and the remote rain forests of northern Queensland, Australia, where a new fungal disease has devastated colonies, populations, and species of tropical frogs. The fungus is highly prevalent in wild bullfrogs, which can be considered asymptomatic reservoirs. The chytrid fungus was detected in bullfrogs produced intensively on open-plan frog farms in South America. These farms export hundreds of thousands of bullfrogs to restaurants in the United States each year.[10]

Biodiversity Buffers the Spillover of Emerging Diseases

The ecological impacts of humans can ripple throughout ecological communities. The demise of one species or the rise of one species at the expense of another may establish a cascade of ecological responses.[1,2] The spread of Lyme disease as a result of the changing ecology of white-tailed deer (*Odocoileus virginianus*) and white-footed mice (*Peromyscus leucopus*) in a landscape devoid of large predators and diminished biodiversity is a good example of ecological magnification of disease.[6]

Biodiversity loss and habitat fragmentation from increased conversion of land to agricultural use may influence the pattern of distribution of Hantavirus host communities. Other community attributes are connected to biodiversity loss and potential spread of hantavirus to human communities. Competent Hantavirus reservoir populations, such as *Oligoryzomys fulvescens* (reservoir for Choclo virus) and *Zygodontomys brevicauda* (reservoir for Calabazo virus), could be influenced by species richness, evenness, diversity, and interspecific interactions within their community, particularly where fragmented landscapes are dominant. Suzan *et al.*[11] hypothesized that a competent reservoir population will increase when left alone, regardless of habitat type, and that the highest infection rates will occur when these competent reservoirs are the dominant species. In poor and tropical communities, landscape change can lead to major shifts in disease patterns; for example, after forest clearing, flooding induces dysentery and cholera outbreaks.[12]

Transdisciplinary Collaboration the Only Way to Success

Examples of new, collaborative, transdisciplinary approaches to diseases of wildlife and domestic animals have been highlighted as part of the growing discipline of conservation

medicine, focusing on a more proactive approach to surveillance, health assessment, and monitoring of wildlife populations as well as health and disease interactions with anthropogenic change and the ecological footprint.[1] This approach will ultimately allow for predictive models and a prompt regional and global response to infectious disease spread. A proactive/predictive approach to future outbreaks and the development of an agenda for environmental management of zoonotic diseases are necessary. Attempts to identify migratory flyways, to determine habitat requirements and characteristics along those flyways, and protect reproduction, nesting, and overwintering wetlands for several migratory bird species are essential. As those habitats are protected, the rates of contact with domestic animals should decrease.[13]

Strategies for a better understanding of wildlife–domestic animal–human disease interactions include (1) fostering collaboration among disciplines; (2) funding surveillance for emerging diseases in wildlife; and (3) identifying species that may serve as sentinels of ecosystem health. Sentinel species can be selected for their ability to reflect environmental perturbations. Based on their life history and physiological attributes, selected species can provide insightful information about environmental changes at various spatial, temporal, and trophic scales.[14,15] Given the complexity of ecosystems, sentinel species should be thought of as being specific to particular environmental conditions during a pandemic. In some cases, an assemblage of species may be suitable for providing an "umbrella" effect in monitoring the cumulative impacts of multiple environmental variables that create the complexity of an emerging disease.

Conflicts of Interest

The authors declare no conflicts of interest.

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