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Biodiversity Conservation and Human Health: Synthesis

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Biodiversity Conservation and Human Health

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Andrés Gómez and Elizabeth Nichols

Introduction

Current levels of *anthropogenic* environmental disturbance have led to unprecedented loss of biodiversity at a global scale. Human health directly and indirectly depends on the goods and services provided by biodiversity, and thus can be negatively affected by its loss. The World Health Organization (WHO), among others, has highlighted that the linkages between biodiversity and human health have been the focus of much recent attention (WHO, 2006). Because goods and services provided by biodiversity are critical for maintaining human health, health has become a conservation topic.

In this synthesis, we present an overview of the current understanding of links between biodiversity and human health, as well as the health implications of biodiversity loss and conservation actions. Here we use the WHO's definition of health, which includes physical, mental, and social stability (WHO, 1946). We define the term biodiversity as *"the variability among living organisms from all sources including,* inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems"* (Convention on Biological Diversity, Article 2). We divide the linkages between biodiversity and health into two categories (direct and indirect), discuss the evidence that supports them, and touch upon cases that illustrate the potential conflicts between biodiversity conservation and public health.

In this document, we use the WHO's Ecosystems program and its linkages as the backbone of our review. Our intention is to provide a succinct compilation of the links as described by the WHO and supported by the scientific literature, and *not* to present the reader with the notion that *all* of biodiversity at *all* times will have a net positive effect on human health. To this end, we have included questions for critical analysis and that highlight: 1) even when there is evidence for a strong positive association, it may be only supplied by a limited subset of species under certain specific ecological contexts; 2) in some cases, links depend upon the functioning of ecosystems at spatial and/or temporal scales that are not amenable to traditional conservation action; and 3) there are many instances in which biodiversity *unfriendly* practices will result in significant improvements in human health. Finally, we want to make the reader aware of the fact that the explicit consideration of the interface between biodiversity conservation and human health is a relatively new field in rapid development. The linkages between biodiversity and human health *"are not usually easy to unravel, describe, or understand, because of their complexity, not their absence"* (Osofsky et al., 2000). We expect that the future will bring additional evidence for those linkages outlined here, as well as a better understanding of functions and services that are not included in this review.

It is safe to say that without the natural world - without plants, microorganisms, fungi, animals, and other components of biological diversity – humans would cease to exist. Some measure of biological diversity and its interactions are absolutely required to sustain human life – and, therefore, human health. A more pragmatic question to ask, perhaps, is how much? Which species, in populations of what sizes, and/or which interactions are required for humans to not only have access to clean water, food, and shelter, but also to enjoy cultural or spiritual fulfillment, happiness, and security?

"Ecosystem services" is the term coined to represent the benefits people gain from ecosystems (MEA, 2005). As the concept of ecosystem services has evolved into the common practice of valuing them, and incorporating those values into the human economy as a conservation practice, the definition has narrowed slightly, and can be currently considered as "the components of nature, directly enjoyed, consumed or used to yield human well-being" (Boyd and Banzhaf, 2007). The difference can be thought of as the difference in describing an ecosystem good as either a pollinated apple or apple pollination, with the value of the former encompassing the ecosystem functions (including soil formation, water, and atmospheric regulation, as well as bee pollination) of the latter.

This distinction effectively outlines the various ways humans and human health depend on, or relate to, biological diversity, and therefore to biodiversity conservation. We can describe direct linkages between human health and biodiversity as including "ecosystem services" and more indirect linkages as connections between humans and 'ecosystem functions'.

Biodiversity and Human Health: Direct Linkages

Humans depend on several ecosystem services. A short list could include a continuous food supply and good nutrition, pharmaceutical products and medical models, as well as "sentinel" species that act as bellwethers for environmental change.

Food Supply and Nutrition

Humans are dependent on managed, semi-wild, and wild ecosystems for a continuous food supply (Waltner-Toews and Lang, 2000). An adequate provision and diversity of food resources is critical to maintaining the daily caloric and nutrient intake required for basic human health. Reductions in the magnitude and stability of food supplies can lead to malnourishment, a major threat to health and well-being. Childhood and maternal malnutrition alone account for 10% of the global *disease burden*, and an estimated 824 million people are malnourished on a regular basis (Corvalan et al., 2005).

Human health and biodiversity directly relate through food in two broad ways. First and most simply, all of the food (and many key vitamins and minerals) that we consume is derived from a plant, fungus, or animal species. People meet their daily caloric and nutritional needs through some combination of wild and domesticated sources. People use wild sources of food in both developed and underdeveloped areas, though wild edible species often are disproportionately critical to meeting the dietary requirements of the rural poor (WRI et al., 2005). Current levels of environmental change and biodiversity loss, coupled with overexploitation are threatening globally important food sources, such as marine (Orensanz et al., 1998; Baum et al., 2003) and freshwater fisheries (Abramovitz, 1996), and wild mammals (Jerozolimski and Peres, 2003; Marshall et al., 2006). As a result many human communities are now hunting, fishing, and collecting less-preferred food supplies (de Merode et al., 2004). In other cases, the resultant scarcity of a food item (e.g., many types of seafood) has rendered them more valuable and thus subject to greater harvest pressure.

Adequate provision and diversity of food is critical for basic human health. Source: K. Frey

Second, wild species are critical to the human food supply as

Critical Thinking Box

The Millennium Ecosystem Assessment, and countless authors and scientists, argue for the preservation and conservation of natural habitats on the premise that degradation of the ecosystem services they provide will undermine human welfare. Yet such degradation has resulted in enormous gains in human health and well-being (Ghazoul, 2007). For example, consider the benefits of fertilizers and industrial agriculture to the human food supply (even as certain segments of the human society begin to face health concerns from *over* rather than *under* consumption) along with their tremendous environmental impacts (Pollan, 2006). *What are some of the repercussions of human agricultural expansion? Does this represent a gain in human health at the cost of "overall" health? What are some of the spatial and temporal trade-offs involved in these gains and losses?*

a genetic library for the future selection of plants and animals more suitable to ever-changing agricultural ecosystems. Also, increased genetic diversity within agricultural systems often confers a degree of resistance to plant pests and pathogens (Lavelle et al., 2004), which can otherwise affect large areas in which only one susceptible species or genotype is planted (Zhu et al., 2000).

Pharmaceuticals and Other Molecules

Vascular plants and their extracts, but also mosses, fungi, and animal parts, have been the main source of traditional medicine since prehistoric times (Table 1).

The importance of nature as a source of medicinal compounds and other molecules with therapeutic properties has not diminished over time; many are currently used to treat pain, fever, high blood pressure, anxiety, and improve heart function. New drugs are continually being discovered, and it may be that nature holds the key to cures for currently untreatable conditions and *emerging infectious diseases*. Compounds found in nature may provide new protection against diseases such as HIV/AIDS, as well as resistant strains of bacteria and cancer. Bacterial infection remains a particularly serious threat to human health, with years of use (and misuse) of common antibiotics having led to the evolution of resistant bacterial strains. Indeed, several strains are resistant to multiple antibiotics, and at least one strain of bacteria is resistant even to the newest antibiotics on the market. It is important to keep our therapeutic arsenal well-stocked and new antibiotic compounds derived from natural sources, which can potentially fight infections with these resistant strains, have recently been identified (Wang et al., 2006). When a species goes extinct, biodiversity is lost and the potentially useful compounds are lost with it.

Table 1. Illustrative list of commonly used drugs derived from natural sources

Drug	Purpose	Source
Amoxicillin	Antibiotic	Fungus
Captopril	Antihypertensive	Animal
Digitoxin	Cardiotonic	Plant
Morphine	Analgesic	Plant
Penicillin	Antibiotic	Fungus
Quinine	Antimalarial, antipyretic	Plant
Salicin	Analgesic	Plant
Vinblastine	Antitumor	Plant
Exenatide	Antidiabetic	Animal
Ecteinascidin	Antitumor	Animal
Ziconotide	Analgesic	Animal

In addition to new medicines, molecules derived from living beings have other positive impacts on human health. For example, a group of molecules derived from a bacterium found in thermal waters in Yellowstone National Park (USA) became the basis for the polymerase chain reaction, a procedure that allows researchers to make multiple copies of DNA molecules (Chien et al., 1976) and to diagnose infectious diseases and genetic disorders, among other important biomedical applications. Molecules derived from animals (e.g., spiders) and plants (e.g., neem tree) also provide newer and safer insecticides and pesticides, (see section 2.1.).

The therapeutic compounds derived from nature have enormous social value. In fact, it has been estimated that at least 80% of the world's population relies on compounds derived chiefly from plants as their main source of health care (Fabricant and Farnsworth, 2001; Kumar, 2004). The importance of medicines derived from living things is not limited to the developing world. More than half of the most commonly prescribed drugs in the United States come from, are derived from, or are patterned after one or more compounds originally found in a live organism (Grifo et al., 1997).

Medical Models

Species belonging to many different taxa are, and will continue to be, invaluable in biomedical research. Biological diversity contributes to human health by playing a critical role in advancing our understanding of human behavior, anatomy, physiology, and disease. The use of these models in research has provided insights that may have been impossible to obtain otherwise. In some cases, a species may be irreplaceable as a disease model; for example, nine-banded armadillos are unique for the study of human leprosy.

Early research and training tools for medical professionals were based on experimentation with animal models. Even today, the use of animals for teaching basic anatomy and surgical procedures to medical students is a common practice in many countries. Animal species are also used to assess the efficacy of new vaccines, anesthetics, and other chemicals with potential therapeutic effects. Such new drugs must be proven to be both effective and safe in vertebrate models that include mice, rats, dogs, and non-human primates before human trials can be conducted.

Medical models are also used to understand the metabolism of particular systems or of the whole body under specific environmental circumstances. Species as diverse as plants and yeasts are routinely used as models to further our understanding of molecular processes, such as gene expression and mutation, providing insights into human health issues like tumor formation and aging. Finally, animals and their cell and tissue cultures serve to advance our knowledge of the effects of specific diseases on human cells, tissues, and organs.

Mice and rats are routinely used as laboratory animals. However, several less common species are used in biomedical research, including horseshoe crabs (for anatomical research), cone snails (for the study of the physiology of cell receptors, neurotransmitters, and ion channels), and sea squirts (for the study of the formation of kidney stones).

Sentinels

The study of the distribution, abundance, and/or health of certain species can provide valuable information about environmental stressors such as chemical pollution or the presence of pathogens, which can potentially threaten human health (Table 2). These species are the proverbial "canary in the coal mine" and are referred to as sentinels because they can warn of potential human health risks. Species belonging to many different taxa, from mosses to dolphins, can serve as sentinels; in general, non-domesticated species are more frequently used as sentinels of both chemical/physical hazards and infectious agents (Rabinowitz et al., 2005).

The distribution and abundance of certain key species can indicate that a specific environmental stressor is currently acting or has been present in the recent past in a particular ecosystem; for example, the disappearance of certain species of mollusks indicates when water pollution has reached a harmful threshold (Funes et al., 2006). Clues about the quality of the environment can also be gleaned by monitoring health parameters in selected species. Many species accumulate pollutants in their tissues, for example, and can therefore provide an accurate picture of the long-term flows of such pollutants through the atmosphere, water, or the food web (Schintu et al., 2005; Alleva et al., 2006). The exposure of sentinel species

Table 2. Illustrative list of organisms used to monitor specific environmental stressors potentially deleterious to human health		
Species	**Sample**	**Environmental Stressor**
Marine/freshwater invertebrates	Distribution and abundance	Chemical pollution
Mosses	Tissue	Chemical pollution
Wild birds	Egg shells, feathers, blood, tissue	Chemical pollution
Amphibians	Distribution and abundance, deformities	Multiple/undetermined
Sea turtles	Pathological changes	Multiple/undetermined
Sea otters	Distribution and abundance, blood, tissue	Chemical pollution, ecosystem integrity
Chickens	Blood	Viral exposure
Wild birds and mammals	Blood	Viral exposure
Lichens	Distribution and abundance	Air pollution
Domestic mammals	Blood	Viral exposure, chemical pollution

to specific infectious agents is regularly used to estimate the human infection risk; for example, wild and domestic birds and mammals are commonly employed as sentinels of *arbovirus* activity (Komar, 2001; Komar et al., 2001; Peterson et al., 2004). In other cases, the detection of specific pathological changes in sentinel species may suggest that multiple sources of environmental change are acting simultaneously with deleterious health effects. The emergence of tumors in sea turtles, for example, may be indicative of more than one source of anthropogenic environmental change in the world's oceans (Aguirre and Lutz, 2004).

These examples demonstrate how species diversity may benefit human health by enabling human populations to detect and react to situations where their health would otherwise be compromised. However, further research is needed to identify the appropriate sentinels for specific health risks in specific environments. Also, even when a certain kind of environmental alteration can be detected, quantified, or monitored through the use of sentinel species, a direct link to human health may not always be present (Rabinowitz et al., 2005).

Biodiversity and Human Health: Indirect Linkages

Our dependence on the natural world extends not only to the final goods and products provided by nature (ecosystem services), but also to the ecosystem processes provided by large-scale ecosystem interactions (see the NCEP module: *Why is Biodiversity Important?*). Ecosystem functions, such as pollination, pest control, soil creation and maintenance, nitrogen fixation, and a host of aquatic processes, support all productive ecosystems. Pollination by diverse groups of wild, unmanaged species and domesticated pollinators such as the European honeybee (*Apis mellifera*) (Kremen et al., 2002) enables the production of approximately one third of the average human daily caloric intake (McGregor, 1976; Buchmann and Nabhan, 1997). Natural biological control of plant pests can help maintain crop yields without investment in artificial chemicals that have negative (and often poorly understood) impacts on both human and animal health (Shetty, 2002). Ecosystem "engineering" by corals and oysters in marine and estuarine environments create habitat for a huge diversity of organisms, many of which are key players in marine and coastal food webs that benefit humans. Nutrient cycling is critical for the persistence of both natural and wild ecosystems (John et al., 2007) and mediated by a large and diverse group of bacteria, protozoa, fungi, and invertebrates.

These processes are representative of the many natural processes that can be indirectly linked to human health. The strength of the evidence supporting these linkages, however, is variable and there is often little direct research connecting declines in these services to concomitant declines in human health. This is because ecosystem processes are time and space extensive, and result from the concerted action of many organisms. Hence, extrapolating 1:1 relationships between human health (which is itself complex and multi-factorial) and biodiversity through the lens of ecosystem services is challenging. Additionally, both the study of biodiversity and ecosystem functioning (BEF) and of the explicit relationship between human health and the environment are new areas of research, and thus are undergoing a period of rapid growth and refinement.

Hydrological Control

Clean water, free from biotic and chemical pollutants, is an essential resource for all humans. The capture and slow filtration of water through naturally vegetated watersheds reduces sediment and organic component loads, a process commonly referred to as water purification (Haines et al., 1993). Much of the developed world can afford water treatment facilities, which mimic this ecosystem service at a financial cost. However, for at least two billion people, these services are unavailable. Over one billion people currently lack access to clean water supplies and water-related infectious disease is estimated to cause more than 3.2 million deaths annually (Corvalan et al., 2005). While it is well understood that the preservation of natural vegetation in watersheds is linked to the availability of clean water supplies downstream, the mechanisms for these ecological functions are only grossly resolved.

One form of hydrologic regulation is flood control. Floods are the world's most frequent natural disaster and often the most costly in both economic and human health terms. Intact wetlands, for example, are valued for their ability to reduce the frequency and magnitude of flooding events at local watershed scales (Andreassian, 2004) by securing soil sediment, and increasing or maintaining soil porosity and infiltration capacity (Bronstert et al., 2000; Tollan, 2002).

Study of the linkages between naturally vegetated ecosystems and hydrology is an extremely active avenue of research. Several recent findings run contrary to the conventional wisdom that forested landscapes are unequivocally beneficial for flood control. While successful in limiting the magnitude and frequency of flood events, the *afforestation* of naturally non-forested ecosystems for the purposes of flood control often instigates soil salinization, resulting in diminished soil fertility and tremendous losses in agricultural productivity, as well as below- and above-ground biodiversity (Jobbagy and Jackson, 2004). Naturally forested watersheds typically exhibit in-

Intact ecosystems play a role in flood mitigation and its mpacts on human health, Source: K. Frey creased stream flow, higher evaporative water loss, lower soil moisture, and reduced groundwater recharge relative to deforested watersheds (Jobbagy and Jackson, 2004). In studies of the effects of tree cover *removal* on flood events, the observed effects are most pronounced at small scales and for frequent flood magnitudes (Tollan, 2002). At larger scales, the effects of deforestation on flooding can be negligible (Mudelsee et al., 2003).

Intact ecosystems play a role in mitigating flood events and, therefore, the primary and secondary impacts of floods on human health (e.g., physical destruction, water- and vector-borne disease outbreaks, and water and soil contamination (Ahern et al., 2005). Flood events are associated with an increased risk of vector-borne (e.g., malaria, dengue, West Nile Fever), water-borne (e.g., cholera, leptospirosis), and non-epidemic, water-borne infection (e.g., wound infections, dermatitis). However, the overall risk for disease outbreak is often low unless there is significant population displacement and/or water sources are compromised; even when this happens, the risk of outbreaks can be minimized with rapid disaster response (Gayer and Connolly, 2005). As such, the strongest linkages between human health and flooding tend to be found in the developing world (Conti et al., 1984; Greenough et al., 2001). Only one of the 14 major floods that occurred globally between 1970 and 1994 (Sudan in 1980) led to a major diarrheal disease outbreak (WHO, 2006). Floods may spur an increase in vector-borne diseases through the expansion in the number and extent of vector habitats (Gayer and Connolly, 2005). The major risk factors for outbreaks associated with flooding are water-borne disease following the contamination of drinking-water facilities, and leptospirosis, a zoonotic bacterial disease that is instigated by rodent population booms following heavy rainfall-induced flooding events (Gayer and Connolly, 2005).

Waste Removal and Decomposition

Excrement from livestock, wildlife, and humans (particularly in rural areas with poor sanitation) is removed by a suite of macro-invertebrates, including dung beetles, termites, and earthworms. The global value of fecal waste removal services was estimated at USD 2.277 trillion in 1997 (Costanza,1997). Dung beetles lay their eggs within a dung mass or more commonly relocate dung below the soil surface – actions which serve to significantly reduce the amount of dung remaining on the soil surface (Lindquist, 1933). Potential linkages between human health and dung beetles include the suppression of dung-breeding fly populations (Horgan and Fuentes, 2005), and the reduction in the transmission of endoparasites and protozoa through contact with contaminated dung (Bryan, 1973; Mathison and Ditrich, 1999; Nichols et al., 2008). In contrast, several authors have suggested that rapid and efficient dung removal by dung beetles allows humans to repeatedly visit defecation areas, potentially increasing rather than decreasing the risk of parasite exposure (Miller, 1954). Additional epidemiological research will be required to identify the positive or negative effects of dung beetle activity on human parasites and pathogens.

Critical Thinking Box

Approximately 14 species of dung beetles live in and near New York City, USA. Dung beetles remove large quantities of dung from the forest surface, suppress fly populations, and may reduce the transmission of endoparasites, like nematodes, from livestock and wildlife to humans. However, they require large blocks of forest cover and dung resources from diverse mammal communities to maintain these services. *Are dung beetles important enough to human health to use their services as an impetus for conservation? Even in the face of modern medicine and expensive land? Are their services substitutable with technology, such as waste treatment facilities? Are their services even required, as wildlife in human-dominated areas declines?*

The decomposition of dead organic matter by biological entities is a critical ecological function carried out by many species belonging to different taxa, but primarily by bacteria and fungi. The term "bioremediation" refers to the technology of using biological processes to remove pollutants from the environment. The term encompasses the methods for facilitating the establishment, growth, and reproduction of the organisms involved, as well as the technologies used to improve the efficiency of the removal processes (including genetic engineering) (Kulkarni and Chaudhari, 2007; Padmavathiamma and Li, 2007; Saier, 2007; Zhuang et al., 2007). Environmental managers interested in removing harmful chemicals from water, soil, or even man-made surfaces (e.g., concrete), take advantage of natural metabolic processes to break them down into harmless metabolites or store them in living tissue. Bioremediation is used for the removal of a wide variety of pollutants, including heavy metals, industrial solvents, hydrocarbons, and pesticides, and is considered an efficient, safe, and cost-effective method for cleaning contaminated environments (Kulkarni and Chaudhari, 2007; Saratale et al., 2007; Shi et al., 2007; Urik et al., 2007; Xu et al., 2007)

Biotic Regulation

Biodiversity can act as a buffer for disease by helping to control the populations of *vectors* and *hosts* involved in disease transmission cycles. In general terms, the loss of any species or functional group with a regulatory role in an ecosystem will lead to drastic increases in the abundance of the species it normally regulates. For example, the loss of carnivorous predators can lead to an explosion in prey populations and the diseases for which they are hosts (Packer et al., 2003; Ostfeld and Holt, 2004; Stronen et al., 2007), although recent evidence suggests that the opposite effect can result under certain ecological conditions (Holt and Roy, 2007). In this section, we highlight two ways in which higher diversity leads to lowered disease prevalence.

The dilution effect

Lyme disease, a tick-borne infection, is one of the most common vector-borne diseases in the United States. Larval and nymphal ticks acquire the infection during a blood meal taken from an infected vertebrate. White-footed mice are the most *competent* host for Lyme disease in the United States; other species vary in their *competence* levels.

Empirical and theoretical evidence support the idea that vertebrate diversity can act as a buffer for Lyme disease incidence in humans, i.e., high vertebrate diversity lowers the risk of human exposure to certain infectious diseases. The dilution effect, as stated by Van Burkirk and Ostfeld (1998) and Ostfeld and Keesing (2000b), proposes that, for Lyme disease, increasing species diversity in the host community reduces the incidence of infected vectors by increasing the probability an uninfected tick will feed on hosts other than mice (Ostfeld et al., 2002). In more species-rich communities, the prevalence of infected vectors (nymphal infection prevalence, NIP) is lower (Figure 1). A recent study found that, in the United States, higher richness of small mammals and lizards is correlated with lower Lyme disease incidence in humans (Ostfeld and Keesing, 2000b).

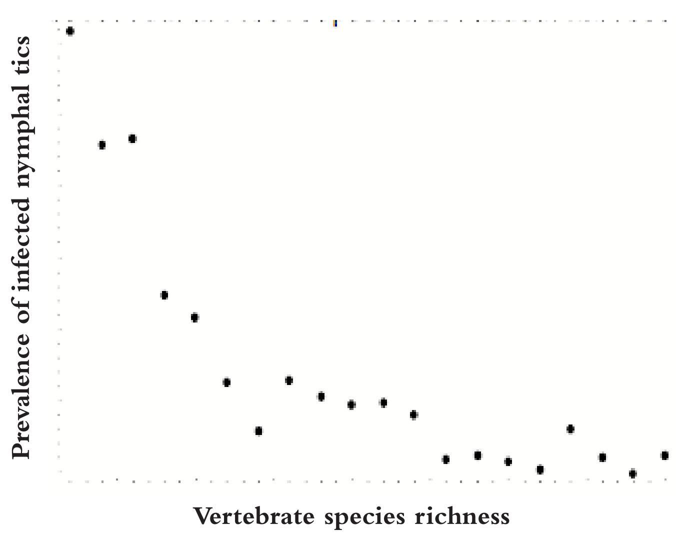

Figure 1. The dilution effect: Prevalence of infected nymphal ticks (a proxy for human Lyme disease risk) as a function of vertebrate species richness. Modified from the model by Schmidt and Ostfeld (2001).

A theoretical exploration of the dilution effect model finds that it hinges upon four basic conditions: 1) the vector must be a generalist; 2) vectors must acquire the infection orally; 3) competence must vary among the species present in the community; and 4) the most competent species must be the most abundant (Ostfeld and Keesing, 2000a). Although it has been suggested that the dilution effect describes a common mechanism by which biodiversity lowers the risk of disease, further evidence is needed to assess its generality. However, the dilution effect provides a powerful argument for biodiversity conservation in areas in which Lyme disease is endemic.

Recent studies have found evidence in favor of the dilution effect in diseases other than Lyme disease. For example, the prevalence of West Nile virus infection in humans and mosquitoes is reduced in areas with higher diversity of non-passerine bird species (Ezenwa et al., 2006), and higher species richness lowers the prevalence of a flea-borne bacterial infection in rodents (Telfer et al., 2005). In addition, mathematical models of disease transmission suggest that high species diversity lowers overall disease prevalence in other disease transmission cycles (Dobson, 2004; Rudolf and Antonovics, 2005). However, the net effects of species diversity over disease incidence could depend on the pathogen's mode of transmission; in these models, species diversity increases disease incidence if pathogen transmission depends on the density of susceptible hosts (Dobson, 2004).

The dilution effect explains a mechanism by which high species richness provides a direct benefit to human health. Addressing the drivers of biodiversity loss in areas where certain diseases are prevalent can serve the dual purposes of conserving species and improving human health.

The buffering effect

Similar to the dilution effect, the buffering effect describes the reduced prevalence of directly transmitted (i.e., not vector-borne) diseases in areas of higher diversity. The buffering effect, first demonstrated for hantavirus infection in Panama, is postulated to be the result of multi-species interactions that lead to regulation of the abundance of pathogen hosts (Suzan, 2005). In this case, experimental species removals resulted in increased hantavirus prevalence. Highly diverse communities have lower densities of hantavirus hosts and thus lower overall disease prevalence. The opposite was found to be true for low diversity ecosystems (Suzan, 2005). Note that while the *dilution effect* modulates the intensity of infection in the disease vectors, the *buffering effect* is concerned with the abundance of hosts with different competence levels.

Atmospheric Regulation

Forest biodiversity can act as a carbon sink, by taking carbon from the atmosphere (carbon dioxide, CO^2, is one of the main greenhouse gases) and converting it into plant biomass (Harper et al., 2007; Kirby and Potvin, 2007) through a process called carbon sequestration. Corals, and many organisms with calciferous body parts, participate in global carbon cycles by metabolizing both organic and inorganic carbon through photosynthesis, respiration (Ridgwell et al., 2003), and the calcification process (Gattuso et al., 1999). Because of these sequestration processes, forest and coral reef conservation are considered important parts of the global strategy to mitigate the negative effects of fossil fuel emissions (Malhi et al., 2002), potentially including the negative effects on human health.

The effects of global climate change are expected to affect the incidence of several infectious and non-infectious human diseases (Rogers and Randolph, 2000; Patz et al., 2005). Since disease vectors are highly dependent on humidity and temperature for reproduction and development, in regions where climate change is expected to lead to higher mean temperatures and increases in rainfall, the incidence of vector-borne diseases is expected to increase (Rogers and Randolph, 2000; Patz, 2001; Epstein, 2002; Patz et al., 2005;). Global warming is also predicted to increase the altitudinal and latitudinal range of vector-borne diseases by extending the total land area that meets the minimum temperatures necessary for vector development. Global climate change places an additional burden on human health through non-infectious effects, such as increased mortality due to extreme heat and cold events (Patz et al., 2005).

Critical Thinking Box

It is sometimes suggested that linking biodiversity to general human well-being considerably broadens the number of links between humans and biodiversity, indeed so broadly that attempts to draw these connections may be fruitless. *Do you think this is the case? Review the linkages described by this synthesis between human health and the natural world. Can you think of others? Do they impact the quality of human life, without fitting into the box of "human health"?*

Psychological Health

It has been argued that biodiversity has beneficial effects on psychological health because:

1) Natural settings provide opportunities for relaxation, exercise, and leisure for millions of people; and
2) Contact with nature can be associated with increased rates of recovery for patients under treatment.

Grifo and Chivian (1999) suggest the following as evidence of the relationship between biodiversity and psychological well-being:

- Patients offered views of nature showed accelerated recovery from surgery and rehabilitation;
- Inmates offered views of nature sought health care less frequently;
- Nature-related activities were selected most often by recovering cancer patients;
- College students with views of nature have a higher capacity for concentration; and
- Contact with nature may help reduce mental fatigue.

Finally, for many people, cultural survival and community cohesion is tied to specific activities that depend on natural resources, e.g., whale hunting or berry picking. Although, a direct connection to human health is difficult to measure in these cases, the protection of the specific ecosystems in which these activities take place is tied to the preservation of these traditional practices, and the concomitant sense of identity and belonging, which, in turn, form part of the larger concept of human well-being.

Well-being is the state of having the basic materials for a secure, good life – a state that encompasses aspects of a secure and adequate livelihood, good social relations, security and personal safety from natural and human-made disasters, freedom of choice and action, and, importantly, good health (Mooney et al., 2005). We use the concept of well-being to illustrate that wild nature has an impact on people's lives that cannot be confined to the narrow definitions of human "health." The loss of local biodiversity has impacts on human well-being that run the gamut from lost jobs, migration, or

A woman cradles a langur in Cuc Phoung,Vietnam,Source: K. Frey lowered tourism revenue, to the collapse of entire civilizations (Balmford and Bond, 2005).

Conflicts Between Human Health and Biodiversity Conservation

The information presented, thus far, suggests that there are links between biodiversity and human health. However, the net effects of environmental change on human disease risk may depend on specific ecological contexts (Ostfeld et al., 2002; Holt and Roy, 2007). The strength and generality of the links previously outlined are then still in need of research.

Some forms of environmental change, while positive for biodiversity, may have negative consequences for human health. For example, forest regeneration was associated with higher risk of leishmaniasis in Sudan (Gratz, 1999), while in the United States, reforestation of abandoned farmland is associated with higher risk of Lyme disease (Telford III, 2002). An unexpected result of some marine mammal conservation efforts has been the increased incidence of intestinal worm infestations in fish and humans (McCarthy and Moore, 2000; Olson et al., 2004).

In other cases, the most environmentally destructive forms of anthropogenic alteration may be associated with the least risks for human health. Clear-cut logging results in relatively low contact rate between humans and wild animals and, therefore, carries less risk of disease emergence than selective extraction (Wolfe et al., 2005). Oil-palm agriculture replaced natural forests in Sarawak and, in the process, reduced the populations of four species of malaria vectors (Gratz, 1999). Similarly, cattle-ranching and sugar cane cultivation reduced the populations of malaria vectors in Honduras (Reid, 1997).

Emerging infectious diseases in humans may pose a unique challenge to biodiversity conservation. Most are *zoonotic*, many with wild animal *reservoirs* . Humans are at risk of disease from close contact with wildlife species, and eradication of wildlife may be seen as the only option available. Although the efficacy of culling wildlife reservoirs has been questioned, and the prevention of disease transmission events through other means has been advocated, the eradication of wildlife species is still considered a valid strategy for use in such disease control efforts (Donnelly et al., 2006).

Potential conflicts between the objectives of conservation biology and those of public health are also of interest when considering the issue of pathogen conservation. Pathogens are critical players in ecological and evolutionary processes. The interactions between pathogens and their hosts have resulted in the evolution of complex biological systems. Pathogens act as powerful selection agents and are drivers of genetic diversity in their hosts, and, by changing host distribution and abundance, affect the diversity of other species in the ecosystem. Pathogen species are themselves a major component of the planet's diversity and represent unique evolutionary lineages. For these reasons, some conservation biologists have argued for the need for conservation of pathogen species (Gompper and Williams, 1998; Windsor, 1998).

Conclusion

The health of humans, and of all other species on the planet, is ultimately connected through our shared ecological realities. Health is, therefore, a unique lens through which to view and attempt to understand the effects of human activities. We have shown that there are direct and indirect linkages between biodiversity and human health. Human activities that lead to loss of biological diversity can also have deleterious consequences for human health and well-being. However, the impacts of these links on the practice of conservation biology are not always straightforward.

To understand the links between human health and biodiversity conservation further research is needed. In particular, we need to investigate their strength and generality. Additionally, our current understanding of these links strongly suggests that not all biodiversity will have a positive net effect on human health (i.e., biodiversity can also have a neutral effect, and some species and ecological processes can even have a negative net effect on humans). Accurately connecting biodiversity to the provision of goods and services will increase our capacity to properly assess their value relative to human health, and to design and implement adequate conservation strategies. Human health depends on a series of complex interactions among environmental, social, economic, and public health factors, and the relative importance of each may differ in different regions, and also change over time. A recent study found no correlation among global indicators of biodiversity loss and human health (Huynen et al., 2004), suggesting that these relationships are better studied at different scales, or that, currently, improvements in public health policies have disproportionately improved human health in the face of great environmental destruction. The multi-factorial nature of the dynamic balance we call "health" suggests that multi-disciplinary approaches involving the fields of biomedical science, public health, conservation biology, anthropology, sociology, ecology, and earth science are needed to better understand the environmental and social determinants of human health risks.

Anthropogenic environmental alteration can negatively affect human health by increasing the incidence of non-infectious diseases and diminishing ecosystem resilience; for example, deforestation and fossil fuel emissions (due to their role in global climate change) may increase the extent and magnitude of the damage caused by extreme weather events. However, biodiversity loss may not be involved as a causal agent of these increased health risks, but may instead be a concurrent consequence of human activities.

The relationship between environmental alteration, biodiversity loss, and changes in disease risks is complex and the causal links are not always clear. Anthropogenic environmental change is considered an important driver of severely negative impacts on human health. The emergence of infectious diseases of plants, animals, and humans, for example, is often linked to human activities (Table 3).

Even when we understand the direct and indirect links between biodiversity and human health, the goods and services involved may accrue at spatial and temporal scales that are intractable for regular conservation initiatives. To illustrate, the biochemical compounds found in nature are the result of processes taking place in evolutionary time, and the regulatory services mediated by biodiversity, even at the local scale, often depend on interactions among processes happening at distant locations. Those situations in which biodiversity conservation can have negative outcomes for human health should be carefully evaluated in a conservation context. However, the health consequences of biodiversity loss are an important consider-

Table 3. Illustrative list of diseases in which environmental alteration is considered to have played a role in emergence or reemergence

Disease	Alteration factors	Geographical Extent	References
Malaria	Deforestation	Latin America	Walsh et al., 1993
Nipah virus	Encroachment, agricultural intensification	South East Asia	Daszak et al., 2001
Hookworm	Deforestation leading to silting	Haiti	Lilley et al., 1997
Hemorrhagic viruses	Land use changes, encroachment	South America	Enria et al., 1998
Leishmaniasis	Deforestation	Latin America	Patz et al., 2000
Schistosomiasis	Intensive irrigation	Africa	Patz et al., 2000
Filariasis	Irrigation, standing water	Asia	Dzodzomenyo et al., 1999
Arboviral diseases	Deforestation, irrigation, agriculture	Global	Molyneux, 2003
Lyme disease	Habitat fragmentation	USA	Allan et al., 2003

ation for environmental policy and such linkages between biodiversity and health will likely remain a powerful motivator for conservation action.

Terms of Use

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Literature Cited

Abramovitz, J. N. 1996. Imperiled waters, impoverished future: the decline of freshwater ecosystems. Page 80. Worldwatch Paper, Washington, D.C.

Aguirre, A. A. and P. A. Lutz. 2004. Marine turtles as sentinels of ecosystem health: is fibropapillomatosis an indicator? EcoHealth 1:275-283.

Ahern, M., R. S. Kovats, P. Wilkinson, R. Few, and F. Matthies. 2005. Global health impacts of floods: epidemiologic evidence. Epidemiologic Reviews 27:36-46.

Allan, B. F., F. Keesing, and R. S. Ostfeld. 2003. Effect of forest fragmentation on Lyme disease risk. Conservation Biology 17:267-272.

Alleva, E., N. Francia, M. Pandolfi, A. M. De Marinis, F. Chiarotti, and D. Santucci. 2006. Organochlorine and heavy-metal contaminants in wild mammals and birds of Urbino-Pesaro province, Italy: An analytic overview for potential bioindicators. Archives of Environmental Contamination and Toxicology 51:123-134.

Andreassian, V. 2004. Waters and forests: from historical controversy to scientific debate Journal of Hydrology 291:1-27.

Balmford, A. and W. Bond. 2005. Trends in the state of nature and their implications for human well-being. Ecology Letters 8:1218-1234.

Baum, J. K., R. A. Myers, D. G. Kehler, B. Worm, S. J. Harley, and P. A. Doherty. 2003. Collapse and conservation of shark populations in the Northwest Atlantic. Science 299:389.

Boyd, J. and S. Banzhaf. 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63:616-626.

Bronstert, A., A. Jaeger, A. Guntner, N. Hauschild, P. Doll, and M. Krol. 2000. Integrated modelling of water availability and water use in the semi-arid Northeast of Brazil. Physics and Chemistry of the Earth Part B: Hydrology Oceans and Atmosphere 25:227-232.

Bryan, R. P. 1973. The effects of dung beetles activity on the numbers of parasitic gastrointestinal helmintic larvae recovered from pasture samples. Australian Journal of Agricultural Research 24:161-168.

Buchmann, S. and G. Nabhan 1997. The Forgotten Pollinators. Island Press, Washington DC.

Chien, A., D. B. Edgar, and J. Trela. 1976. Deoxyribonucleic acid polymerase from the extreme thermophile Thermus aquaticus. Journal of Bacteriology 174:1550-1557.

Conti, J. A., D. J. Forrester, R. K. Frohlich, G. L. Hoff, and W. J. Bigler. 1984. Helminths of urban gray squirrels in Florida. Journal of Parasitology 70:143-144.

Corvalan, C., S. Hales, and A. McMichael. 2005. Ecosystems and human well-being: health synthesis: a report of the Millennium Ecosystem Assessment. World Health Organization. Available from: http://www.millenniumassessment.org/en/Products.Synthesis.aspx

Costanza, R., R. dArge, R. deGroot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. Oneill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.

Daszak, P., A. A. Cunningham, and A. D. Hyatt. 2001. Anthropogenic environmental change and the emergence of infectious diseases in wildlife. Acta Tropica 78:103-116.

de Merode, E., K. Homewood, and G. Cowlishaw. 2004. The value of bushmeat and other wild foods to rural households living in extreme poverty in Democratic Republic of Congo. Biological Conservation 118:573-581.

Dobson, A. 2004. Population dynamics of pathogens with multiple host species. American Naturalist 164:S64-S78.

Donnelly, C. A., R. Woodroffe, D. R. Cox, F. J. Bourne, C. L. Cheeseman, R. S. Clifton-Hadley, G. Wei, G. Gettinby, P. Gilks, H. Jenkins, W. T. Johnston, A. M. Le Fevre, J. P. McInerney, and W. I. Morrison. 2006. Positive and negative effects of widespread badger culling on tuberculosis in cattle. Nature 439:843-846.

Dzodzomenyo, M., S. K. Dunyo, C. K. Ahorlu, W. Z. Coker, M. A. Appawu, E. M. Pedersen, and P. E. Simonsen. 1999. Bancroftian filariasis in an irrigation project community in southern Ghana. Tropical Medicine & International Health 4:13-18.

Enria, D. A., A. M. Briggiler, and M. R. Feuillade. 1998. An overview of the epidemiological, ecological and preventive hallmarks of Argentine haemorrhagic fever (Junin virus). Bulletin De L'Institut Pasteur 96:103-114.

Epstein, P. R. 2002. Biodiversity, climate change and emerging infectious diseases. Pages 27-40 in A. A. Aguirre, R. Ostfeld, G. M. Tabor, C. House, and M. C. Pearl, editors. Conservation medicine: ecological health in practice. Oxford University Press, New York.

Ezenwa, V. O., M. S. Godsey, R. J. King, and S. C. Guptill. 2006. Avian diversity and West Nile virus: testing associations between biodiversity and infectious disease risk. Proceedings of the Royal Society B 273:109-117.

Fabricant, D. S., and N. R. Farnsworth. 2001. The value of plants used in traditional medicine for drug discovery. Environmental Health Perspectives 109:69-75.

Funes, V., J. Alhama, J. I. Navas, J. Lopez-Barea, and J. Peinado. 2006. Ecotoxicological effects of metal pollution in two mollusc species from the Spanish South Atlantic littoral. Environmental Pollution 139:214-223.

Gattuso, J., M. Frankignoulle, and S. V. Smith. 1999. Measurement of community metabolism and significance of coral reefs in the CO2 source-sink debate. Proceedings of National Academy of Sciences USA 96:13017-13022.

Gayer, M. and M. Connolly. 2005. Communicable Disease Control After Disasters. Chapter 5 in E. Noji, editor. Public Health Consequences of Disasters. Oxford University Press, Oxford.

Ghazoul, J. 2007. Recognising the complexities of ecosystem management and the ecosystem service concept. Gaia-Ecological Perspectives for Science and Society 16:215-221.

Gompper, M. E. and E. S. Williams. 1998. Parasite conservation and the black-footed ferret recovery program. Conservation Biology 12:730-732.

Gratz, N. G. 1999. Emerging and resurging vector-borne diseases. Annual Review of Entomology 44:51-75.

Greenough, G., M. McGeehin, S. M. Bernard, J. Trtanj, J. Riad, and D. Engelberg. 2001. The potential impacts of climate variability and change on health impacts of extreme weather events in the United States. Environmental Health Perspectives 109:191–198.

Grifo, F. and E. Chivian. 1999. The implications of biodiversity loss for human health. Pages 197-208 in J. Cracraft, and F. Grifo, editors. The Living Planet in Crisis: Biodiversity Science and Policy. Columbia University Press, New York.

Grifo, F., D. Newman, A. S. Fairfield, B. Bhattacharya, and J. T. Grupenhorf. 1997. The Origin of Prescription Drugs.

Pages 131-164 in F. Grifo, and J. Rosenthal, editors. Biodiversity and Human Health. Island Press, Washington, D.C.

Haines, A., P. R. Epstein, A. J. McMichael, M. Hughjones, C. F. Hutchinson, L. S. Kalkstein, S. A. Lloyd, S. S. Morse, N. Nicholls, M. Parry, J. Patz, S. Postel, K. Sherman, and R. Slooff. 1993. Global Health Watch: Monitoring Impacts of Environmental Change. Lancet 342:1464-1469.

Harper, R. J., A. C. Beck, P. Ritson, M. J. Hill, C. D. Mitchell, D. J. Barrett, K. R. J. Smettem, and S. S. Mann. 2007. The potential of greenhouse sinks to underwrite improved land management. Ecological Engineering 29:329-341.

Holt, R. D. and M. Roy. 2007. Predation can increase the prevalence of infectious disease. American Naturalist 169:690-699.

Horgan, F. G. and R. C. Fuentes. 2005. Asymmetrical competition between Neotropical dung beetles and its consequences for assemblage structure. Ecological Entomology 30:182-193.

Huynen, M., P. Martens, and R. S. De Groot. 2004. Linkages between biodiversity loss and human health: a global indicator analysis. International Journal of Environmental Health Research 14:13-30.

Jerozolimski, A., and C. Peres. 2003. Bringing home the biggest bacon: a cross-site analysis of the structure of hunter-kill profiles in Neotropical forests. Biological Conservation 111.

Jobbagy, E. G. and R. B. Jackson. 2004. Groundwater use and salinization with grassland afforestation. Global Change Biology 10:1299-1312.

John, R., J. W. Dalling, K. E. Harms, J. B. Yavitt, R. F. Stallard, M. Mirabello, S. P. Hubbell, R. Valencia, H. Navarrete, M. Vallejo, and R. B. Foster. 2007. Soil nutrients influence spatial distributions of tropical tree species. Proceedings of the National Academy of Sciences 104:864-869

Kirby, K. R. and C. Potvin. 2007. Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. Forest Ecology and Management 246:208-221.

Komar, N. 2001. West Nile virus surveillance using sentinel birds. Pages 58-73 in D. White and D. Morse, editors. West Nile Virus: Detection, Surveillance, and Control. New York Academy of Sciences, USA.

Komar, N., N. A. Panella, and E. Boyce. 2001. Exposure of domestic mammals to West Nile Virus during an outbreak of human encephalitis, New York City, 1999. Emerging Infectious Diseases 7:736-738.

Kremen, C., N. Williams, and R. Thorp. 2002. Crop pollination from native bees at risk from agricultural intensification. Proceedings of National Academy of Sciences USA 99:16812-16816.

Kulkarni, M. and A. Chaudhari. 2007. Microbial remediation of nitro-aromatic compounds: An overview. Journal of Environmental Management 85:496-512.

Kumar, P. 2004. Valuation of medicinal plants for pharmaceutical uses. Current Science 86:930-937.

Lavelle, P., M. Blouin, J. Boyer, P. Cadet, D. Laffray, A. T. Pham-Thi, G. Reversat, W. Settle, and Y. Zuily. 2004. Plant parasite control and soil fauna diversity. Comptes Rendus Biologies 327:629-638.

Lilley, B., P. Lammie, J. Dickerson, and M. Eberhard. 1997. An increase in hookworm infection temporally associated with ecologic change. Emerging Infectious Diseases 3:391-393.

Lindquist, A. 1933. Amounts of dung buried and soil excavated by certain Coprini (Scarabaeidae). Journal of the Kansas Entomological Society 6:109-125.

Malhi, Y., P. Meir, and S. Brown. 2002. Forests, carbon and global climate. Philosophical Transactions of the Royal Society of London Series A: Mathematical Physical and Engineering Sciences 360:1567-1591.

Marshall, A. J., Nardiyono, L. M. Engstrom, B. Pamungkas, J. Palapa, E. Meijaard, and S. A. Stanley. 2006. The blowgun is mightier than the chainsaw in determining population density of Bornean orangutans (Pongo pygmaeus morio) in the forests of East Kalimantan. Biological Conservation 129:566-578.

Mathison, B. and O. Ditrich. 1999. The fate of Cryptosporidium parvum oocysts ingested by dung beetles and their possible role in the dissemination of cryptosporidiosis. Journal of Parasitology 85:687-681.

McCarthy, J. and T. A. Moore. 2000. Emerging helminth zoonoses. International Journal for Parasitology 30:1351-1360.

McGregor, S. E. 1976. Insect Pollination Of Cultivated Crop Plants in C. H. B. R. Center, editor. USDA.

MEA. 2005. Millennium Ecosystem Assessment Synthesis. Pages 1-219 in W. Reid, H. A. Mooney, A. Cropper, D. Capistrano, S. R. Carpenter, K. Chopra, P. Dasgupta, T. Dietz, A. Duraiappah Kumar, R. Hassan, R. Kasperson, Rik Leemans, R. M. May, T. A. J. McMichael, P. Pingali, C. Samper, R. Scholes, R. T. Watson, A. H. Zakri, Z. Shidong, N. J. Ash, E. Bennett, P. Kumar, M. J. Lee, C. Raudsepp-Hearne, Henk Simons, J. Thonell, and M. B. Zurek, editors. World Resources Institute, Washington D.C., USA.

Miller, A. 1954. Dung Beetles (Coleoptera, Scarabaeidae) and other insects in relation to human feces in a hookworm area of southern Georgia. American Journal of Tropical Medicine and Hygiene 3:372-389.

Molyneux, D. H. 2003. Common themes in changing vector-borne disease scenarios. Transactions of the Royal Society of Tropical Medicine and Hygiene 97:129-132.

Mooney, H. A., A. Cropper, D. Capistrano, S. R. Carpenter, K. Chopra, P. Dasgupta, R. Leemans, R. M. May, P. Pingali, R. Hassan, C. Samper, R. Scholes, R. T. Watson, A. H. Zakri, Z. Shidong, T. Dietz, and A. Duraiappah Kumar. 2005. Ecosystems and Human Well-being Synthesis. Pages 1-155 in W. Reid, editor. World Resources Institute, Washington, D.C., USA.

Mudelsee, M., M. Borngen, G. Tetzlaff, and U. Grunewald. 2003. No upward trends in the occurrence of extreme floods in central Europe. Nature 425:166-169.

Nichols, E., S. Spector, J. Louzada, T. Larsen, S. Amezquita, M. Favila, and the Scarabaine Research Network. 2008. Ecological functions and ecosystem services provided by Scarabaeine dung beetles. Biological Conservation.

Olson, R. E., J. R. Pierce, K. C. Jacobson, and E. M. Burreson. 2004. Temporal changes in the prevalence of parasites in two Oregon estuary-dwelling fishes. Journal of Parasitology 90:564-571.

Orensanz, J. M. L., J. Armstrong, D. Armstrong, and R. Hilborn. 1998. Crustacean resources are vulnerable to serial depletion - the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Reviews in Fish Biology and Fisheries 8:117-176.

Osofsky, S. A., W. B. Karesh, and S. L. Deem. 2000. Conservation medicine: a veterinary perspective. Conservation Biology 14:336-337.

Ostfeld, R., and F. Keesing. 2000a. The function of biodiversity in the ecology of vector-borne zoonotic diseases. Canadian Journal of Zoology: Revue Canadienne De Zoologie 78:2061-2078.

Ostfeld, R. S. and F. Keesing. 2000b. Biodiversity and disease risk: The case of Lyme disease. Conservation Biology 14:722-728.

Ostfeld, R. S. and R. D. Holt. 2004. Are predators good for your health? Evaluating evidence for top-down regulation of zoonotic disease reservoirs. Frontiers in Ecology and the Environment 2:13-20.

Ostfeld, R., F. Keesing, E. M. Schauber, and K. A. Schmidt. 2002. Ecological context of Lyme disease: biodiversity, habitat fragmentation, and risk of infection. Pages 207-220 in A. A. Aguirre, R. Ostfeld, G. M. Tabor, C. House, and M. C. Pearl, editors. Conservation medicine: ecological health in practice. Oxford University Press, New York.

Packer, C., R. D. Holt, P. J. Hudson, K. D. Lafferty, and A. P. Dobson. 2003. Keeping the herds healthy and alert: implications of predator control for infectious disease. Ecology Letters 6:797-802.

Padmavathiamma, P. K. and L. Y. Li. 2007. Phytoremediation technology: Hyper-accumulation metals in plants. Water Air and Soil Pollution 184:105-126.

Patz, J. A. 2001. Public health risk assessment linked to climatic and ecological change. Human and Ecological Risk Assessment 7:1317-1327.

Patz, J. A., D. Campbell-Lendrum, T. Holloway, and J. A. Foley. 2005. Impact of regional climate change on human health. Nature 438:310.

Patz, J. A., T. K. Graczyk, N. Geller, and A. Y. Vittor. 2000. Effects of environmental change on emerging parasitic diseases. International Journal for Parasitology 30:1395-1405.

Peterson, A. T., N. Komar, O. Komar, A. Navarro-Siguenza, M. B. Robbins, and E. Martinez-Meyer. 2004. West Nile virus in the New World: potential impacts on bird species. Bird Conservation International 14:215-232.

Pollan, M. 2006. The Omnivore's Dilemma: A Natural History of Four Meals Penguin Press, NY, USA.

Rabinowitz, P. M., Z. Gordon, R. Holmez, B. Taylor, M. Wilcox, D. Chudnov, P. Nadkarni, and F. J. Dein. 2005. Animals as sentinels of human environmental health hazards: An evidence-based analysis. EcoHealth 2:26-37.

Reid, W. V. 1997. Opportunities for Collaboration Between the Biomedical and Conservation Communities. Pages 334-353 in F. Grifo, and J. Rosenthal, editors. Biodiversity and Human Health. Island Press, Washington, DC.

Ridgwell, A. J., A. J. Watson, M. A. Maslin, and J. O. Kaplan. 2003. Implications of coral reef buildup for the controls on atmospheric CO^2 since the Last Glacial Maximum. Paleoceanography 18(4): 1083.

Rogers, D. J. and S. E. Randolph. 2000. The global spread of malaria in a future, warmer world. Science 289:2283-2284.

Rudolf, V. H. W. and J. Antonovics. 2005. Species coexistence and pathogens with frequency-dependent transmission. American Naturalist 166:112-118.

Saier, M. H. 2007. Beneficial bacteria and bioremediation. Water Air and Soil Pollution 184:1-3.

Saratale, G., S. Kalme, S. Bhosale, and S. P. Govindwar. 2007. Biodegradation of kerosene by Aspergillus ochraceus NCIM-1146. Journal of Basic Microbiology 47:400-405.

Schintu, M., A. Cogoni, L. Durante, C. Cantaluppi, and A. Contu. 2005. Moss (Bryum radiculosum) as a bioindicator of trace metal deposition around an industrialised area in Sardinia (Italy). Chemosphere 60:610-618.

Schmidt K. A. Ostfeld R. S. 2001 Biodiversity and the dilution effect in disease ecology. Ecology 82(3): 609-619.

Shetty, P. K. 2002. Ecological implications of pesticide use in agro-ecosystems in India. Page 7. National Pesticide Stewardship Alliance, Bangalore.

Shi, D. Q., Z. Jian, Z. L. Gui, D. Jian, T. L. Wang, V. Murygina, and S. Kalyuzhnyi. 2007. Bioremediation of oil sludge in Shengli oilfield. Water Air and Soil Pollution 185:177-184.

Stronen, A. V., R. K. Brook, P. C. Paquet, and S. McLachlan. 2007. Farmer attitudes toward wolves: Implications for the role of predators in managing disease. Biological Conservation 135:1-10.

Suzan, G. 2005. The responses of hantavirus host communities to habitat fragmentation and biodiversity loss in Panama. Page 98. Department of Biology. University of New Mexico, Albuquerque, U.S.A.

Telfer, S., K. J. Bown, R. Sekules, I. Begon, T. Hayden, and R. Birtles. 2005. Disruption of a host-parasite system following the introduction of an exotic host species. Parasitology 130:661-668.

Telford III, S. R. 2002. Deer tick-transmitted zoonoses in the Eastern United States in A. A. Aguirre, R. Ostfeld, G. M. Tabor, C. House, and M. C. Pearl, editors. Conservation medicine: ecological health in practice. Oxford University Press, New York.

Tollan, A. 2002. Land-use change and floods: what do we need most, research or management? Water Science and Technology 45:183-190.

Urik, M., S. Cernansky, J. Sevc, A. Simonovicova, and P. Littera. 2007. Biovolatilization of arsenic by different fungal strains. Water Air and Soil Pollution 186:337-342.

Van Buskirk, J. and R. S. Ostfeld. 1998. Habitat heterogeneity, dispersal, and local risk of exposure to Lyme disease. Ecological Applications 8:365-378.

Walsh, J. F., D. H. Molyneux, and M. H. Birley. 1993. Deforestation: effects on vector-borne disease. Parasitology 106:S55-S75.

Waltner-Toews, D. and T. Lang. 2000. A new conceptual base for food and agricultural policy: the emerging model of links between agriculture, food, health, environment and society. Global Change & Human Health 1:116-130.

Wang, J., S. M. Soisson, K. Young, W. Shoop, S. Kodali, A. Galgoci, R. Painter, G. Parthasarathy, Y. S. Tang, R. Cummings, S. Ha, K. Dorso, M. Motyl, H. Jayasuriya, J. Ondeyka, K. Herath, C. Zhang, L. Hernandez, J. Allocco, Ã. n. Basilio, J. R. Tormo, O. Genilloud, F. Vicente, F. Pelaez, L. Colwell, S. H. Lee, B. Michael, T. Felcetto, C. Gill, L. L. Silver, J. D. Hermes, K. Bartizal, J. Barrett, D. Schmatz, J. W. Becker, D. Cully, and S. B. Singh. 2006. Platensimycin is a selective FabF inhibitor with potent antibiotic properties. Nature 441:358-361.

WHO, World Health Organization. 1946. Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York.

WHO, World Health Organization. 2006. Ecosystems and health.

Windsor, D. A. 1998. Equal rights for parasites. Bioscience 48:244-244.

Wolfe, N. D., P. Daszak, A. M. Kilpatrick, and D. S. Burke. 2005. Bushmeat hunting deforestation, and prediction of zoonoses emergence. Emerging Infectious Diseases 11:1822-1827.

WRI, U. N. D. Programme, U. N. E. Program, and W. Bank. 2005. The Wealth of the Poor: Managing Ecosystems to Fight Poverty. WRI, Washington DC.

Xu, G. M., Y. Y. Li, W. Zheng, X. Peng, W. Li, and Y. C. Yan. 2007. Mineralization of chlorpyrifos by co-culture of Serratia and Trichosporon spp. Biotechnology Letters 29:1469-1473.

Zhu, Y. Y., H. R. Chen, J. H. Fan, Y. Y. Wang, Y. Li, J. B. Chen, J. X. Fan, S. S. Yang, L. P. Hu, H. Leung, T. W. Mew, P. S. Teng, Z. H. Wang, and C. C. Mundt. 2000. Genetic diversity and disease control in rice. Nature 406:718-722.

Zhuang, P., Q. W. Yang, H. B. Wang, and W. S. Shu. 2007. Phytoextraction of heavy metals by eight plant species in the field. Water Air and Soil Pollution 184:235-242.

Glossary

Afforestation: the process of establishing a forest on land that is not forested, or has not been a forest for some time.

Anthropogenic: derived from or caused by human activities.

Arbovirus: arthropod-borne virus. Refers to viruses with an arthropod vector, such as West Nile and dengue fever viruses.

Competent: see Competence.

Competence: the capacity of a host to pass the infection on to an uninfected vector.

Disease burden: a measure of the amount of disease caused by a specific factor or group of factors.

Emerging infectious disease: a disease that has recently increased in incidence, expanded its geographical or host range, is newly recognized, or has recently evolved.

Host: the individual or species that is infected by a pathogen.

Reservoir: an individual, population, or species that harbors an infection, but is generally not affected by it and can thus act a source for infection for others.

Vector: an organism, most frequently an arthropod, capable of transmitting a disease through bites. For example, mosquitoes are the vectors for the malaria parasite and ticks transmit the bacterium causing Lyme disease.

Zoonotic: a disease that is shared among animals and humans.