Illustrative Bibliography for Exploring "Health as an Ecosystem Service":

January 2010 Compilation

The Wildlife Conservation Society organized a December, 2009 forum to explore the question, "Can health be economically quantified as an ecosystem service, correlated with ecosystem intactness and if so, under what circumstances?" To provide for a richer discussion, we've compiled an illustrative (not exhaustive) set of annotated readings exploring five dimensions of this question.

The first section reviews diseases correlated in some way with environmental change. The next section covers human attributes particularly affected by the disease / environment relationship and addresses other species intersecting with these linkages. Section III summarizes the literature on anthropogenic changes contributing to human disease. Section IV reviews specific ecological and other environmental factors affecting disease occurrence. The last section covers environmental and health economics, market mechanisms for valuing ecosystem services, and challenges linking health and the environment economically.

These annotations represent only a subset of the literature (recent peer review publications for which abstracts are web-available). Emphasis was on articles referencing both health and the environment and at a landscape or seascape scale, ideally with an economic dimension. Select articles covering a single dimension are included to round out the readings. Many articles touched on various dimensions of the following framework and are included where they contribute most directly to the section question.

We hope you find these materials helpful.

<u>I. What dimensions of health should be our focus (infectious disease, non-infectious disease, nutrition, psychological health)? What major human diseases are currently flagged in the literature as correlated with ecosystem alterations?</u>

1) Conceptual frameworks and overarching syntheses

Myers SS and Patz JA (2009) Emerging Threats to Human Health from Global Environmental Change *Annu Rev Environ Resour* 34:223–52

This chapter explores how changes in land use, climate, and the function of ecosystems may act synergistically to alter exposure to infectious disease and natural disasters and curtail access to food, clean air, and clean water – basic components of the public's health. It focuses on the greatest emerging threats from climate and large-scale, anthropogenic changes to landscapes and natural systems for ecosystem services: food production and clean water provision. These

are difficult to study using traditional approaches as they are multi-factoral and complex and often occur over very large scales.

Ample evidence exists regarding alterations to disease transmission; most but not all show increases. Mechanisms by which changes occur include: changes in the density or presence of disease-related organisms; changes in exposure pathways; and changes in community species composition. Food and water scarcity combined with greater vulnerability to natural disasters may lead to much higher morbidity and mortality e.g. from malnutrition and chronic hunger, particularly in SSA and parts of SE Asia experiencing ecological constraints to local food production due to soil degradation and water scarcity. Water is also needed for drinking, sanitation, hygiene, and food preparation - inadequate access causes millions of deaths. Climate change is expected to worsen water scarcity.

Depletion of ecosystem services might impact health only when resources are very constrained and a threshold is reached. Vulnerability to natural disasters (fires, floods, storms, tidal waves, landslides) influences how changing environmental conditions may impact human health. Vulnerability differs by socioeconomic status and by gender (especially women) and age.

Myers SS (2009) Global Environmental Change: The Threat to Human Health in Worldwatch Report 181, Worldwatch Institute

Over the past two-to-three hundred years, humanity's ecological footprint has ballooned to such an extent that we are now fundamentally altering the planet. We have transformed the Earth's land surface and altered the function of its ecosystems, and we are triggering the rapid loss of both terrestrial and marine life. We are also profoundly changing our planet's climate. It is increasingly apparent that the breadth and depth of the changes we are wreaking on the environment are imperiling not only many of the other species with which we share the ecological stage, but the health and wellbeing of our own species as well. Global climate change threatens human health in numerous and profound ways. Large segments of the population will experience more heat waves, altered exposure to infectious disease, and more-frequent natural disasters. Most significantly, climatic disruption threatens the adequacy of the core "building blocks" of health for large populations around the globe: sufficient food and nutrition, safe water for drinking and sanitation, fresh air to breathe, and secure homes to live in. As climate change dismantles these central elements of healthy societies, people with fewer resources will be forced to migrate in large numbers to lands where they may not be welcome. A likely result of all of these processes will be increased civic instability and strife.

Sala OE, Meyerson LA, Parmesan C (2009) (eds) Biodiversity Change and Human Health: From Ecosystem Services to Spread of Disease, Island Press

This book summarizes discussions at a 2005 SCOPE/Diversitas/UNESCO workshop on Biodiversity, Health and the Environment. Four key "biodiversity

drivers" were identified: quality of life, medicinal and genetic resources, constraints on infectious disease and ecosystem services.

Chivian E, Bernstein A (2008) (eds) Sustaining Life: How Human Health Depends on Biodiversity, Oxford University Press

This book examines the full range of potential threats of biodiversity loss on human health, i.e., human medicine, biomedical research, the emergence and spread of infectious diseases, and the production of food, both on land and in the oceans.

Prüss-Üstün A, Bonjour S, Corvalán C (2008) The Impact of the Environment on Health by Country: a Meta-Synthesis *Environmental Health* 7:7 doi: 10.1186/1476-069X-7-7

WHO data on the environmental burden of disease for 192 countries quantify health impacts of three major environmental risk factors: 'unsafe water, sanitation & hygiene', 'indoor air pollution from solid fuel use' and 'outdoor air pollution'. The preventable health impact from environmental improvements is estimated at 13%-37% of country disease burden. Over 25% of child deaths in 20 lowest income countries could be prevented from safe water, sanitation and hygiene, and safer fuels for cooking.

US Environmental Protection Agency/ National Center for Environmental Research (EPA/NCER) (2006) Biodiversity and Human Health: A Multidisciplinary Approach to Examining the Links (meeting proceedings)

EPA/NCER has proposed a joint Ecosystem-Health Research Program to study the links between changes in biodiversity and risks to human health. In co-sponsorship with Yale University's Center for EcoEpidemiology, the Smithsonian Institution, and the World Conservation Union, EPA/NCER convened a forum to discuss the state of the science, refine research priorities, and how to integrate existing data into a monitoring and risk-forecasting network to prevent or significantly mitigate risks of human disease and threats to biodiversity. Priority themes included: epidemiology and vector ecology; climate change, biodiversity, and health; wildlife trade and the spread of exotics and disease; pharmacopeia; the role of biodiversity in natural catastrophes; and valuation of biodiversity for public health.

Aron JL, Patz JA (2001) (eds) Ecosystem Change and Public Health: a Global Perspective, Blackwell Science, Inc

This textbook covers global climate change, ozone depletion, water resources management, and ecology and infectious disease with case studies on cholera, malaria and the effects of water resource limitations.

Wilcox BA (2001) Ecosystem Health in Practice: Emerging Areas of Application in Environment and Human Health *Ecosystem Health* 7(4): 317

Ecosystem health can be described as an emerging area of professional practice. The main purpose of the discipline is to provide environment and health management and policy professionals with a theoretical framework and practical tools to improve society's ability to sustain earth's life-support systems. This article examines how ecosystem health is working to help refocus efforts and lay the groundwork for improved future use.

Grifo F, Rosenthal J (**1997)** (eds) Biodiversity and Human Health, Island Press

This book examines how biodiversity loss affects the spread of human diseases, causes a loss of medical models, diminishes the supplies of raw materials for drug discovery and biotechnology and threatens food production and water quality.

Daily GC, Ehrlich PR (1996) Global Change and Human Susceptibility to Disease *Annual Review of Energy and the Environment* Vol 21 pp 125-144

Human vulnerability to disease is strongly and deleteriously influenced by many alterations to the environment. The book examines threats to human defenses against disease including loss of biodiversity and indigenous knowledge, immune suppression and the evolution of antibiotic resistance.

2) Infectious disease

Bonds MH, et al. (2009) Poverty Trap formed by the Ecology of Infectious Diseases *Proc R Soc B* doi:10.1098/rspb.2009.1778

While most of the world has enjoyed exponential economic growth, more than one-sixth of the global population is today roughly as poor as their ancestors were many generations ago. This paper investigates why such poverty persists. Building on a well-established model of human infectious diseases, the authors reveal how integrating economic and disease ecology models gives rise to poverty "traps" whereby initial economic and epidemiological conditions determine a society's long-term health and economic trajectory. They conclude that the poverty trap can be broken by improving health conditions of the population. Additionally, they demonstrate how simple human ecological models can help explain broad patterns of modern economic organization.

Plowright RK, et al. (**2008)** Causal Inference in Disease Ecology: Investigating Ecological Drivers of Disease Emergence *Front Ecol Environ* 6 doi: 10.1890/070086

The authors suggest strategies to analyze the complex relationship between environmental change and disease emergence and present examples about recent EIDs (Hendra and Nipah viruses and avian influenza).

Ostfeld RS, Keesing F, Eviner VT (2008) (eds) Infectious Disease Ecology: Effects of Ecosystems on Disease and of Disease on Ecosystems**,** Princeton University Press

Diseases sometimes serve to maintain the structure and function of the ecosystems on which humans depend. This book develops a framework for understanding where diseases come from, what ecological factors influence their impacts, and how they in turn influence ecosystem dynamics - shedding light on roles diseases play in ecosystems.

Ayra, N, et al. (2008) Time for an Ecosystem Approach to Public Health? Lessons from two Infectious Disease Outbreaks in Canada *Global Public Health*: 1-19

Ecosystem approaches recognize the complexity of many contemporary public health challenges and offer an alternative for dealing with problems proven to be intractable and unresponsive to conventional public health strategies. Infectious disease outbreaks are among the most dramatic aspects of systems failure. This paper uses the Canadian cases of SARS (Severe Acute Respiratory Syndrome) in Toronto and the *E. coli* outbreak in Walkerton as useful illustrative examples to examine some of the limitations of current public health approaches, the fundamental tenets of an alternative, trans-disciplinary ecosystem approach, and changes necessary for implementation (e.g. philosophical approach, communications and education and institutions and governance).

Rapport DJ (2006) Avian Influenza and the Environment: an Ecohealth Perspective (report submitted to UNEP) http://www.unep.org/dewa/products/publications/2006/DRapport_AI_Final_180506_Edit3.doc.pdf

There is growing concern that the near global reach of a highly pathogenic strain of avian influenza, HPAI H5N1, could spark the next influenza pandemic with a toll potentially running into millions of human lives. Traditional public health measures are rapidly being called into play, with limited success, to prevent further spread of HPAI H5N1. However, left out of the equation (for the most part) are preparations to redress ecological imbalances that have given rise to the threat. This gap calls for the adoption of an ecohealth perspective – one that focuses on the upstream causes of emerging diseases that are root causes of ecosystem degradation and ecological imbalance. Restoring health to the world's ecosystems is an essential aspect of the struggle to reduce human vulnerability to emerging and resurging diseases. An ecohealth approach argues that re-establishing and maintaining healthy ecosystems is the essential precondition for both sustaining human and animal health.

Patz JA, et al. (2005) Ecosystem Regulation of Infectious Diseases Chapter 14 in Ecosystems and Human Well-being: Current State and Trends, Millenium Assessment (MA) Report Vol 1 by Hassan RM, Scholes R, Ash N

Anthropogenic ecological change affecting infectious disease occurs through: altered habitats or breeding sites for disease vectors or reservoirs; niche invasions; loss of predator species; biodiversity change; host transfer; and changes in (intermediate) host population density. Infectious diseases account for 29 of 96 major causes of human morbidity/ mortality or 24% of the global burden of disease. This chapter focuses on diseases with known links to anthropogenic ecological change (infectious and parasitic).

Karesh WB, Cook RA (2005) The Human-Animal Link *Foreign Affairs*: 38-50

In recent years, outbreaks of diseases such as avian flu, SARS and Ebola have led to massive economic loss, jeopardized global commerce and frightened the public. They share a key characteristic, i.e., the ability to cross the divide between animals and people. None of the diseases depends on human hosts for its survival and, consequently, they all persist beyond the reach of medical intervention. This article reviews key issues related to these diseases including obstacles to effectively identifying and addressing them. The authors present the case for a broader, global "one health" approach in order to avoid future infectious disease pandemics.

Daszak P, et al. (2004) Conservation Medicine and a New Agenda for Emerging Diseases *Ann NY Acad Sc* 1026: 1–11

Recent outbreaks of SARS, avian influenza, and others highlight emerging zoonotic diseases as a key threat to global health. The authors highlight Nipah and Hendra viruses as examples and analyze underlying drivers.

Molyneux DH (2003) Common Themes in Changing Vector-Borne Disease Scenarios *Trans of the Royal Society of Trop Med and Hygiene* 97 (2):129-32

Global burden of disease studies suggest that infectious diseases will contribute a proportionately smaller burden over the next two decades as non-communicable diseases emerge as public health problems. However, infectious diseases contribute proportionately more in the poorest quintile of the population. This paper reviews conditions driving the changing epidemiology of these infections and suggests that the change is linked by common themes e.g. interactions of generalist vectors and reservoir hosts at interfaces with humans, reduced biodiversity associated with anthropogenic environmental changes and land use changes, e.g. hydrological, urbanization, agricultural, mining and forest-associated impacts (extractive activities, road building, deforestation and migration) seen on a global scale.

Taylor LH, Latham SM, Woolhouse MEJ (2001) Risk Factors for Human Disease Emergence *Phil Trans R Soc Lond* B 356, 983- 989
doi: 10.1098/rstb.2001.0888

Of 1415 species of infectious organisms pathogenic to humans, 538 (38%) are bacteria and rickettsia, 307 (22%) fungi, 287 (20.3%) helminthes, 217 (15.3%) viruses and prions and 66 (4.6%) protozoa. Of these, 868 (61%) are zoonotic and 175 (12.4%) associated with EIDs. Among emerging pathogens, 132 (75%) are zoonotic. Protozoa and viruses are particularly likely to emerge and helminthes particularly unlikely to do so, irrespective of zoonotic status. Zoonotic pathogens are twice as likely to become EIDs than non-zoonotic ones. No association apparently exists between transmission route and emergence.

a) Malaria

Malaria is a major public health threat and its association with ecological change has been studied more than other developing country diseases. Alternative preventive strategies are needed Examples include:

Confalonieri U (2005) Saúde na Amazônia: Um Modelo Conceitual Para a Análise de Paisagens e Doenças *Estud av* Vol 19 No 53

This paper proposes a conceptual model involving "Disease Landscapes" for analyzing the epidemiological profile of human populations in the Brazilian Amazon region related to social and environmental dynamics. Three major landscape categories assessed are: natural, anthropic and built - each associated to a well defined set of health outcomes. A comparative analysis is provided of epidemiological dynamics in six malaria landscapes, defined on the basis of land use strategies.

Morel CM, Lauer JA, Evans DB (**2005)** Cost Effectiveness Analysis of Strategies to Combat Malaria in Developing Countries *BMJ* 3;331(7528):1299

Cost effectiveness of selected malaria control interventions in SSA is assessed in the context of reaching the MDGs for malaria. Effects were assessed as DALYs averted through a 10 year implementation program. The impact on population health for various interventions and their combinations was evaluated at selected coverage levels by using a state-transition model. The authors conclude that a much larger infusion of resources than those currently available is needed to make headway in the fight to roll back malaria.

Tanser FC, Sharp B, le Sueur D (2003) Potential Effect of Climate Change on Malaria Transmission in Africa *The Lancet* 362(9398):1792-8

The authors quantitatively assessed the potential effect of projected climate scenarios on malaria transmission in Africa using a spatiotemporally validated model. The model estimated transmission with sensitivity of 63% and specificity of 96% for over 3000 parasite surveys. On average 445 million people are exposed in Africa per year. The model estimates a 5-7% potential increase

(mainly altitudinal) in malaria distribution by 2100 with little increase in latitudinal extents, mostly in areas of existing transmission.

Kitron U (1987) Malaria, Agriculture and Development: Lessons from Past Campaigns *Int J Health Services* 17: 295-326

The author presents an evaluation of several anti-malaria campaigns and the relative contribution of direct measures employed and indirect factors operating during these campaigns. Approaches and factors considered essential or useful for successful malaria control are also identified. In two case studies, direct anti-malaria measures were based mostly on reduction of mosquito breeding and elimination of *Anopheles* larvae. The World Health Organization global anti-malaria campaign is discussed in light of early experiences. The author concludes that no single measure is sufficient to control malaria and that future anti-malaria campaigns need to adopt strategies that are flexible, incorporated into local health services and interrelated with agricultural practices. Moreover, a certain threshold of socioeconomic development, health services infrastructure, and educational level may have to be reached for the successful application and maintenance of direct anti-malaria measures.

b) West Nile

Rochlin I, et al. (2008) Comparative Analysis of Distribution and Abundance of West Nile and Eastern Equine Encephalomyelitis Virus Vectors in Suffolk County, New York, using Human Population Density and Land Use/Cover Data *J Med Entomol* 45(3):563-71

This paper looked at human population density (HPD) and land use/cover (LUC) classification systems to describe mosquito abundance and to determine whether mosquitoes as arbovirus vectors are more common in urban versus residential areas. They found higher abundance and percent composition in rural areas, with increases in freshwater wetland, natural vegetation areas, or a combination.

Brown HE, et al. (2008) Ecological Factors associated with West Nile Virus Transmission, Northeastern USA *Emerg Infect Dis* http://www.cdc.gov/EID/content/14/10/1539.htm

Using disease surveillance data the authors demonstrated significant spatial spreading among increasingly urban counties. Counties with the least (<38%) forest cover had 4.4-fold greater odds of above-median disease incidence than those with the most forest cover quantifying urbanization as a risk factor for West Nile Virus (WNV) disease incidence.

Ezenwa VO, et al. (2006) Avian Diversity and West Nile Virus: Testing Associations between Biodiversity and Infectious Disease Risk *Proc R Soc Lond B Biol Sci* 273: 109–117

Factors accounting for variation in WNV prevalence are poorly understood but links between high biodiversity and reduced vector-borne disease risk may help account for distribution patterns. The authors tested associations between bird diversity (primary host) and both mosquito and human virus infection rates. The number of non-passerine bird species (richness) was significantly negatively correlated with infection rates in both. There was no significant difference for passerine species suggesting the former may play a role in dampening WNV amplification rates in mosquitoes, minimizing human disease risk.

c) Dengue fever

Dengue is a disease of increasing importance linked particularly to rainfall and temperature changes.

Clark DV, et al. (2005) Economic Impact of Dengue Fever/Dengue Hemorrhagic Fever in Thailand at the Family and Population Levels *Am J Trop Med Hyg* 72(6):786-91

In this study, disability adjusted life years (DALYs) lost for fatal and non-fatal cases of dengue were calculated. When accounting for the direct cost of hospitalization, indirect costs due to loss of productivity, and the average number of persons infected per family, the authors observed a financial loss per family more than the average monthly income. The DALYs were of the same order of magnitude as the impact of several diseases currently given priority in South East (SE) Asia (trypanosomiasis, schistosomiasis, malaria, and hepatitis) suggesting that dengue prevention and control should be considered equally important as that of diseases currently given priority.

Hales S, et al. (1999) El Nino and the Dynamics of Vectorborne Disease Transmission *Environmental Health Perspectives* Vol 107, Number 2

The authors calculated correlations between annual El Nino Southern Oscillation (ENSO) index averages, local temperature and rainfall, and dengue fever for different islands in the South Pacific. Findings suggest that climate changes associated with ENSO may trigger an increase in dengue fever transmission in larger, more populated islands where the disease is endemic and propagation of infection from larger islands to smaller neighbors. Transfer between islands appears to be independent of inter-annual climate variations, pointing to the importance of modulating factors in dengue transmission such as population density and travel.

d) Rift Valley Fever

Anyamba A, Linthicum KJ, Tucker CJ (2001) Climate-Disease Connections: Rift Valley Fever in Kenya *Cad Saúde Pública* Vol 17 suppl

Rift Valley fever (RVF) outbreaks in Kenya have followed periods of abnormally high rainfall associated with the warm phase of the ENSO phenomenon. Anomalous rainfall floods mosquito-breeding habitats containing infected mosquito eggs that hatch into mosquitoes transmitting the RVF virus - preferentially to livestock but also to humans. Historical data on RVF outbreaks linked with ENSO indicators reveal close association between inter-annual climate variability and RVF outbreaks in Kenya.

e) Schistosomiasis

King CH, Dickman K, Tisch DJ (2005) Reassessment of the Cost of Chronic Helmintic Infection: a Meta-analysis of Disability-related Outcomes in Endemic Schistosomiasis *The Lancet* Vol 365

Schistosomiasis is one of the world's most prevalent infections yet published disability-adjusted life-year (DALY) estimates suggest that the average effect of schistosome infection is small. The authors conducted a systematic review of disability-associated outcomes for all forms of schistosomiasis to produce an evidenced-based reassessment of schistosomiasis-related disability. Out of 482 reports, 135 were selected for inclusion. Disability-linked morbidities included anaemia, chronic pain, diarrhoea, exercise intolerance, and under-nutrition. The authors calculated pooled estimates (2–15%) of reported disability-related effects using weighted odds ratios for categorical outcomes and standardized mean differences for continuous data. This contrasts with WHO estimates of 0·5% disability weight indicating a need to reassess the importance of this disease.

3) Food security, hunger and malnutrition

Under-nutrition & malnutrition increasing susceptibility to disease affect large numbers of people and are increasing with environmental change. Reduced food production associated with water supply and soil fertility and reduction in wild food sources are among the causes captured in the literature.

Wilby A, et al. (2009) Biodiversity, Food Provision and Human Health in Biodiversity Change and Human Health: From Ecosystem Services to Spread of Disease, Island Press

This chapter reviews food production interactions between biological diversity and human health. Biological diversity provides humans food through harvesting of natural populations (fishing, hunting, grazing of native ecosystems); and farming (terrestrial and aquaculture). In both harvested and farmed systems, increasing production intensity can decrease biological diversity that in turn reduces productivity (e.g. over fishing). Priority should go to preserving extensive yet productive agroecosystems, and incorporating more diversity into relatively intensive agroecosystems.

Scherr SJ, Sthapit S (2009) Farming and Land Use to Cool the Planet in: State of the World 2009: Into a Warming World, Worldwatch Institute

Thousands of Philippine low income farmers who grow crops on steep, deforested slopes, have joined land care groups to boost food production and incomes while reducing soil erosion, improving soil fertility and protecting local watersheds (e.g. strips of natural vegetation are left to terrace their slopes). The farmers have both enriched their landscapes and enhanced food security while helping to cool the planet by cutting greenhouse gas emissions and storing carbon in soils and vegetation.

Amede T, Delve RJ (2008) Modeling Crop–Livestock Systems For Achieving Food Security and Increasing Production Efficiencies in the Ethiopian Highlands *Experimental Agriculture* 44:441-452 doi:10.1017/S0014479708006741

Current cropping systems in southern Ethiopia fulfill nutritional requirements of some communities while others are highly 'food-deficit' from their own farms, i.e., production covers less than seven months per year and fulfills <50% of the recommended daily allowances (RDA) for human nutrition. A linear programming optimization model predicted how to fulfill the RDA as well as cash income needs of respective communities by reallocating cropping areas, reducing soil erosion and the quantity and quality of livestock feed in some areas and crop water requirements in others. The changes did not imply any extra labor.

Friend R, et al. (2007) Aquatic Resources, Food Security and Nutrition in the Lao People's Democratic Republic: A Case Study from Attapeu Province in Poverty Health and Ecosystems: Experience from Asia by Steele P, Oviedo G, and McCauley D (eds) IUCN/ADB

Aquatic resources [fish, amphibians, some reptiles, various invertebrates (prawns, crabs, snails, insects), and varieties of wild aquatic plants] are an important but neglected wild food resource to address food security and poverty reduction in the Lao People's Democratic Republic. Food security is strongly affected by the relationship between aquatic resources and rice. Intensification of rice production could negatively impact wild aquatic resources through conversion of wetland areas, among other factors.

Colfer CJP, Sheil D,Kishi M (2006) People, Forests and Food Chapter 2 in Forests and Human Health: Assessing the Evidence CIFOR Occasional Paper No. 45

Forests are important safety nets for people living in and near forests, especially poor people dependent on forests for food. The nutritional value of many forest foods however is unknown. Forests have poor soils, often with little potential to support intensive agriculture, and plants whose defenses make them inedible without processing. Nevertheless, forests are important genetic reservoirs for wild and semi-wild plants and animals. Forests also supply goods such as fuel indirectly important for the provision and preparation of food. Toxic exposure (e.g. mycotoxin) and viral diseases from wildlife contact negatively affect the health of forest living people. Landscape modification is often motivated by need

for food although some manipulations maintain forest cover while also increasing food production. Logging, hunting and invasive species (plants and animals) change forest composition with location-specific impacts on food availability. Different stages of forest re-growth vary in food productivity.

Silva P (2005) Environmental Factors and Children's Malnutrition in Ethiopia World Bank Policy Research Working Paper 3489 http://econ.worldbank.org

Approximately half of all childhood deaths in developing countries are attributable to mild and moderate malnutrition. Despite some improvement over the past two decades, Ethiopia has one of the highest child malnutrition rates in the world - approximately half of all children under age five. Several biological and social economic factors contribute to the problem. An analysis of 2000 Ethiopia Demographic and Health Survey data revealed that biological factors such as child's age and mother's height and social economic factors such as household wealth and mother's education are important determinants of a child's nutritional status. On the environmental side, the analysis identified significant externalities associated with access to water and sanitation at the community level that affected the probability of children being stunted and/or underweight. Their results showed that the external impact of access to water was larger for children living in rural areas.

Anderson PK, et al. (2004) Emerging Infectious Diseases of Plants: Pathogen Pollution, Climate Change and Agrotechnology Drivers *Trends in Ecology & Evolution* Vol 19, Issue 10

The authors apply the definition of emerging infectious disease (EID) to botany, highlighting a series of emerging diseases of both cultivated and wild plants. Little is known about wild-plant EIDs, the underlying cause of which is anthropogenic introduction of parasites. Severe weather events are also important drivers.

Fa JE, Currie D, Meeuwig J (2003) Bushmeat and Food Security in the Congo Basin: Linkages between Wildlife and People's Future *Environmental Conservation* 30. 1: 71-78 doi:10.1017/S0376892903000067

This paper investigates trends in mammal bushmeat and non-bushmeat protein supply for inhabitants of Congo Basin countries. Supply predictions for the next 50 years were measured as *E*:*P* ratios [extraction (*E*) versus production (*P*)], controlling for deforestation and population growth. At current exploitation rates, wild protein supply will drop 81% in all countries and recommended daily protein requirements will not be met. If harvests are reduced to a sustainable level, almost all countries will still have dramatic losses of wild protein supply. Dependence on bushmeat protein reflects lack of sufficient amounts of non-bushmeat protein to feed growing populations. Protein malnutrition will likely increase dramatically in the region unless food security is promptly addressed and many forest mammals could soon become extinct.

Milner-Gulland EJ, Bennett EL, the SCB 2002 Annual Meeting Wild Meat Group (2003) Wild Meat: the Bigger Picture *Trends in Ecology & Evolution* Vol 18 Issue 7 pp 351-57 doi:10.1016/S0169-5347(03)00123-x

Tropical rural people often rely heavily on wild meat. In many areas this important food source is already lost or being rapidly depleted due to massive overhunting. A mosaic of hunted and no-take areas in a landscape context might balance conservation with continued subsistence use.

Thrupp LA (2000) Linking Agricultural Biodiversity and Food Security: the Valuable Role of Agrobiodiversity for Sustainable Agriculture *International Affairs* Vol 76, Issue 2, pp 283-297

Agricultural biodiversity is critical for food security. This article outlines serious threats from global agrobiodiversity loss and reviews approaches to effectively conserve, use and enhance biodiversity that encourage sustainable food security.

Daily GC, Ehrlich PR (1990) An Exploratory Model of the Impact of Rapid Climate Change on the World Food Situation *Proc R Soc Lond B* 2241:232–44

A globally-aggregated, stochastic-simulation model was used to examine the effects of rapid climatic change on agriculture and human population dynamics. The model suggests that the number of hunger-related deaths could double (compared to an estimated 200 million deaths in the past 20 yrs) if grain production keeps pace with population growth but climatic conditions are unfavorable. If grain production increase does not keep pace with population growth, the number of hunger-related deaths could increase dramatically; the impact of climatic change is relatively small under this scenario. Even favorable climatic changes enhancing agricultural production may not prevent a major increase in death under scenarios where population growth outpaces production.

4) Water, sanitation and hygiene

Graham Environmental Sustainability Institute (2008) Water, Health, and the Environment: Establishing the Research Agenda (conference white papers and abstracts)
http://www.graham.umich.edu/pdf/2008conference-papers.pdf

The relationships between water and human health are becoming more complex and the problems associated with them more urgent. The issues span multiple spatial and temporal scales and thus solutions require interdisciplinary approaches. To create a forum whereby diverse groups could craft interdisciplinary responses, the Graham Environmental Sustainability Institute sponsored a conference, “Water, Health, and the Environment: Establishing the Research Agenda” in March 2008. The conference fostered discussion and collaboration between traditional academic disciplines (e.g., engineering, public health, natural resources, etc.) and industry and governmental agencies. The specific objective was to identify research and assessment needs and

opportunities in support of regional, national, and international sustainable water-human systems. This document presents select conference faculty white papers.

USAID (2007) Investments in Drinking Water Supply Projects and Related Resources Activities (Report to Congress Fiscal Year 2006) http://www.ehproject.org/PDF/ehkm/usaid-water_fy2006.pdf

Water is an essential component to human health, food security, economic growth, security and environmental sustainability. However, poor management of water resources, growing world population and increasing demand are causing serious water shortages. Water security and sustainability with equity simultaneously considers: the need for human access to safe and affordable water for health and well-being, the assurance of economic and political stability, the protection of human populations from risks of water-related hazards, the equitable and cooperative sharing of water resources, the complete and fair valuation of the resource, and the sustainability of ecosystems at all parts of the hydrologic cycle. This report summarizes water management programs that help ensure water security and sustainability with equity i.e., water resources management, water productivity and water-related disaster preparedness. The Agency's investments in drinking water supply projects and related activities reflect the urgent need to provide safe and affordable domestic water supply that is effectively integrated into overall water resources management.

Fewtrell L, et al. (2005) Water, Sanitation, and Hygiene Interventions to Reduce Diarrhoea in Less Developed Countries: a Systematic Review and Meta-analysis *Lancet Infect Dis* (1):42-52

Measures of diarrhoea morbidity in non-outbreak conditions were pooled by meta-analysis as summary estimates of intervention effectiveness. All significantly reduced risk of diarrhoea (relative risk estimates were between 0.63 and 0.75). Water quality interventions (point-of-use water treatment) were very effective and multiple interventions (e.g. combined water, sanitation, and hygiene measures) were not more effective than single focus ones.

Postel SL, Thompson BH (2005) Watershed Protection: Capturing the Benefits of Nature's Water Supply Services *Natural Resources Forum* Vol 29 Issue 2, pp 98 – 108 doi: 10.1111/j.1477-8947.2005.00119.x

Healthy watersheds provide a supply and purification of fresh water. Because these services lie outside the traditional domain of commercial markets, they are undervalued. Development pressures leading to rapid modification of watershed lands is leading to the loss of valuable hydrological services, posing risk to the quality and cost of drinking water and the reliability of water supplies. This article summarizes key attributes of hydrological services and their economic benefits; presents mechanisms for safeguarding those services; and discusses programs in Quito, Costa Rica and New York City.

Cotruvo JA, et al. (2004) (eds) Waterborne Zoonoses: Identification, Causes and Control, World Health Organization, IWA Publishing

Waterborne disease is mainly due to pathogens transmitted faecal–orally and by drinking water, interconnected with shellfish consumption and other fish harvests and indirect exposure to water in foodstuffs. Zoonotic pathogens among these are significant due to various driving forces e.g., ecosystem disturbance, water scarcity and climate change. Animal (domestic and wild) density in catchment basins determines the amount of zoonotic pathogens entering water sources. Pathogens infecting a wide range of animals (domestic and wild) pose more risk than those that infect only one host rarely present in a catchment basin. People lacking improved water supply access and sanitation are at increased risk.

Prüss-Üstün A, et al. (2004) Unsafe Water, Sanitation and Hygiene Chapter 16 in Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors by M. Ezzati et al. (eds), World Health Organization

The global disease burden in 1990 caused by unsafe water, sanitation and hygiene (WSH) was estimated to be 5.3% of all deaths and 6.8% of all DALYs. Specifically, this estimate measures the text to which diarrhoeal and selected parasitic diseases were attributable to WSH risk factors. The burden of some parasitic diseases (schistosomiasis, trachoma, ascariasis, trichuriasis and hookworm disease) was wholly attributable to unsafe WSH. For infectious diarrhoea, the burden was estimated by establishing exposure scenarios according to water supply and sanitation infrastructure, the level of faecal–oral pathogens in the environment and populations assigned to these scenarios. Unsafe WSH is also an important determinant in a number of diseases not included in the above estimates (e.g. malaria, yellow fever, filariasis, dengue, hepatitis A and hepatitis E, typhoid fever, arsenicosis, fluorosis and legionellosis), some of which present a high disease burden at the global level. WSH risk factors include multiple dimensions: the ingestion of unsafe water, lack of water linked to inadequate hygiene, poor personal and domestic hygiene and agricultural practices, contact with unsafe water, and inadequate development and management of water resources or water systems.

Cairncross S, et al. (2003) Health, Environment and the Burden of Disease: a Guidance Note, Department for International Development

Poor households particularly need health to pursue their livelihood. This note examines how environmental hazards cause substantial disease. Three problems account for nearly three quarters of the environmental burden of disease: water, sanitation and hygiene; indoor air pollution; and injuries.

5) Environmental toxins

a) Mercury contamination

Sampaio da Silva D, et al. (2009) Influence of Ecological Factors and of Land Use on Mercury Levels in Fish in the Tapajós River Basin, Amazon *Environmental Research* Vol 109, Issue 4 pp 432-446

This study identified characteristics of aquatic environments associated with high levels of Hg in fish. Multiple regression revealed significantly higher mean Hg levels in key species during descending waters in lotic environments and low waters in lentic environments. Watersheds with high aquatic vegetation cover and low forest cover corresponded to high Hg concentrations in fish and the converse suggesting watershed land uses play a key role in Hg contamination levels of local fish.

Mainville N, et al. (2006) Decrease of Soil Fertility and Release of Mercury following Deforestation in the Andean Amazon, Napo River Valley, *Ecuador Science of The Total Environment* Vol 368, Issue 1, pp 88-98

Studies propose a link between deforestation, soil erosion and leaching of naturally occurring mercury (Hg). Soil erosion exposes the mineral horizon with a higher Hg burden to the elements provoking accelerated leaching. Significant soil erosion and reduced Hg concentrations on soil surfaces suggest deforestation and associated Hg leaching could contribute to fish Hg contamination in the Napo River watershed.

Dorea JG (2003) Fish are Central in the Diet of Amazonian Riparians: Should We Worry about their Mercury Concentrations? *Environmental Research* Vol 92, Issue 3 pp 232-244

The hydrological cycle of the Amazon rain forest determines human disease patterns, agricultural conditions, and food availability. Toxic substances [linamarin in cassava and monomethyl mercury (MMHg) bioconcentrated in fish flesh] cause neurotoxic diseases elsewhere but rarely in Amazonia. The gold rush brought large-scale environmental disruption including a heavy discharge of metallic Hg but it has not yet impacted MMHg concentrations in fish or hair of fish consumers. Fish provides an excellent source of protein and nutrients to these populations, the lack of which could aggravate existing health problems.

Roulet M, et al. (2000) Increase in Mercury Contamination Recorded in Lacustrine Sediments following Deforestation in the Central Amazon *Chemical Geology* Vol 165, Issues 3-4 pp 243-266

This study demonstrates how soil erosion increases surficial sediment mercury concentrations in aquatic systems of the Tapajós and Arapiuns rivers, exploited by human riverine populations. It reveals how environmental changes associated with recent colonization of drainage basins and growing exploitation of new land disturb mineral, organic matter and mercury cycles.

b) Other toxins

De Guise S, Lagace A, Beland P (1994) Tumors in St. Lawrence Beluga Whales (*Delphinapterus leucas*) *Veterinary Pathology* Vol 31, Issue 4, pp 444-449

Necropsied belugas from the polluted estuary of the St. Lawrence River had high tissue concentrations of industrial contaminants known to be carcinogenic and/or immunosuppressive malignant and benign tumors, irrespective of age.

6) Mental health and emotional well being

Speldewinde PC, et al. (2009) A Relationship between Environmental Degradation and Mental Health in Rural Western Australia *Health & Place* Vol 15, Issue 3, pp 880-887

A Bayesian spatial method was used to examine effects of environmental degradation (dryland salinity) on the mental health of rural residents. Dryland salinity and depression were associated suggesting environmental processes are driving the degree of psychological ill-health in these populations.

Zaradic PA, Pergams ORW (2007) Videophilia: Implications for Childhood Development and Conservation *The Journal of Developmental Processes* Vol 2, Issue 1

Direct experience with nature is the most highly-cited influence on environmental attitude and conservation activism in the US. National park visit data suggest a trend away from interactions with nature and a concurrent rise in the use of electronic entertainment media. The latter has been implicated in negative psychological and physical effects including obesity, loneliness, depression, and attentional problems Outdoor play and nature experience on the other hand have proven beneficial for cognitive functioning, increase in self-discipline and emotional well being at all developmental stages.

Horwitz P, Lindsay M, O'Connor M (2002) Biodiversity, Endemism, Sense of Place, and Public Health: Inter-relationships for Australian Inland Aquatic Systems *Ecosystem Health* Vol 7 Issue 4, pp 253 – 265

The authors assert that inland water biodiversity and human health are linked: i) biodiversity contributes to a person's attachment to place and becomes part of their identity. Loss, destruction, or change in location can affect psychological well-being and challenge a community's identity and image of itself, ii) inland waterways contain biota that can directly affect human health when modified. Perceptions of place may change dramatically according to the presence of the biota. Health may be directly affected through control efforts e.g., wetlands, mosquitoes, and arboviruses.

Van Haaften EH, Van de Vijver FJ (1999) Dealing with Extreme Environmental Degradation: Stress and Marginalization of Sahel Dwellers *Soc Psychiatry Psychiatr Epidemiol* 34(7):376-82

Environmental degradation (measured as vegetation cover, erosion, and loss of organic matter) among Sahel dwellers was associated with higher levels of stress, marginalization, passive coping (avoidance), a more external locus of control, and lower levels of active coping (problem solving and support seeking). Variation in all psychological variables was stronger in pastoralists than agriculturalists across all levels of degradation. Women scored higher on stress, (external) locus of control, problem solving and support seeking than men. The study suggested that people display an active approach to environmental degradation if levels are not beyond their control.

II. What attributes of households make environmental health benefits more or less important? Whose health? Human, livestock, wildlife and does it matter? On what socio-economic groups have studies focused? In which geographical and social settings?

The literature points to children and the poor as the most vulnerable subgroups. There are many examples of the role of wildlife in human disease risk, at times mediated through domestic animals. The main geographic focus is tropical forests, reflecting the dominance of literature on mosquito vector-borne diseases.

1) Which human subgroups and geographic areas?

a) Children: Where risk by subgroup has been assessed, children stand out as the priority group, followed by women. Poor people suffer the most.

Patz JA, et al. (2007) Climate Change and Global Health: Quantifying a Growing Ethical Crisis *EcoHealth* 4(4): 397-405

The health burden from climate change is greatest among the world's poor and 88% of this burden afflicts children <5 presenting a major axis of inequity. Major mitigation approaches may produce negative side effects disproportionately among the poor (e.g. competition for land from biofuels affecting food prices) . Society needs to pursue equitable solutions that first protect the most vulnerable population groups, defined by demographics, income, or location.

Shea KM and the Committee on Environmental Health (2006) Global Climate Change and Children's Health *International Journal of Epidemiology* 35(2):213-216

This report specifically reviews the nature of climate change and anticipated health effects on children.

Wells NM, Lekies KS (2006) Nature and the Life Course: Pathways from Childhood Nature Experiences to Adult Environmentalism *Children, Youth and Environments* 16(1): 1-24 http://www.colorado.edu/journals/cye/

Model testing of US urban adult interview data and cross-validation procedures using structural equation modeling suggest that childhood participation with nature may set an individual on a trajectory toward adult environmentalism, i.e., positive attitudes and behaviors relating to the environment.

Smith KR, Corvalán CF, Kjellström T (1999) How Much Global Ill Health Is Attributable to Environmental Factors? *Epidemiology* 10:573-584

25-33% of burden of disease globally is due to environmental risk factors; children < 5 bear the largest burden, and the % of disease due to environmental risks decreases with economic development.

Craig MH, Snow RW, le Sueur DC (1999) A Climate-based Distribution Model of Malaria Transmission in Sub-Saharan Africa *Parasitology Today* Vol 15, No 3, pp 105-111(7)

Malaria remains the single largest threat to child survival in SSA, warranting long-term investment for control. The authors describe a numerical approach to defining malaria transmission distribution based upon climate-associated biological constraints on parasite and vector development as the basis for predicting impact of climate change on transmission.

Brewster D (1999) Environmental Management for Vector Control. Is it Worth a Dam if it Worsens Malaria? *BMJ* 11;319 (7211):651-2

This article reports substantial increase in malaria incidence among children living close to small dams in the Tigray region, northern Ethiopia, compared with more distant villages. Transmission intensity does not correlate directly with morbidity and mortality due to modulating effects of immunity and other factors. Environmental management strategies for vector control include locating dams at high altitude and a range of environmental manipulations.

Loevinsohn ME (1994) Climatic Warming and Increased Malaria Incidence in Rwanda *The Lancet* 343 (8899):714-8

This study assessed the contribution of climate to changes in malaria incidence in Rwanda, increasing 337% in 3 years. The increase was greatest in groups with little acquired immunity--children under 2 years (564%) and people in high-altitude areas (501%). Temperature (mean minimum) predicted incidence best at higher altitudes where malaria had increased most. These findings are most relevant to regions near the altitude or latitude limits of the disease.

b) Indigenous communities

Gracey M, King M (2009) Indigenous Health Part 1: Determinants and Disease Patterns *The Lancet* Vol 374, Issue 9683, pp 65 - 75

The world's indigenous people have low standards of health associated with poverty, malnutrition, overcrowding, poor hygiene, prevalent infections and environmental contamination.

c) Poor underlying health

Beldomenico PM, Begon M (2009) Disease Spread, Susceptibility and Infection Intensity: Vicious Circles? *Trends in Ecology & Evolution* 25 doi:10.1016/j.tree.2009.06.015

Research indicates that host susceptibility should be considered carefully to better understand mechanisms by which parasite dynamics influence host dynamics and vice versa. Insect, fish, amphibian and rodent studies show that infection occurrence and intensity are more probable and more severe in individuals with an underlying poor condition. Infection itself further deteriorates the host creating a 'vicious circle'.

d) Low and middle income countries

Rapport, DJ, Mergler D (2004) Expanding the Practice of Ecosystem Health *EcoHealth* 1 (suppl no. 2): 4-7

Humans are not only disrupters of ecosystem integrity, they also suffer the effects. The effects are not felt equally however as lower and middle-income countries are much more vulnerable. The authors describe an alternative model to studying the complex social, cultural, political and economic situation of these countries and their impact on the environment and human health: an ecosystem approach to human health. They also describe the role of Canada's International Development Research Centre (IDRC) in supporting this approach.

2) Which species

a) Domestic animals

Zinsstag J, et al. (2005) A Model of Animal–Human Brucellosis Transmission in Mongolia *Preventive Veterinary Medicine* 69 (1), pp 77-95

Human disease is commonly caused by exposure to infected livestock and livestock products. Brucellosis is one such major zoonosis, transmitted to humans from both small ruminants (sheep and goats) and cattle. The authors develop a model of livestock-to-human brucellosis transmission as the basis for cost-effectiveness analysis of a nation-wide livestock vaccination program.

Mayen F (2003) Haematophagous Bats in Brazil, Their Role in Rabies Transmission, Impact on Public Health, Livestock Industry and Alternatives to an Indiscriminate Reduction of Bat Population *Journal of Veterinary Medicine* Series B Vol 50 Issue 10, pp 469 – 472 doi: 10.1046/j.1439-0450.2003.00713.x

Three species of Latin American bats feed only on wild bird blood. One causes livestock losses and could be a rabies vector. Human rabies from bat bites increased in Brazil so bats became a control target. Indiscriminate actions (e.g. destroying roosts) negatively affected other bat species extremely important for the ecologic balance. Vaccinating exposed livestock against rabies would protect the endangered livestock and also have public health affect.

International Development Research Centre (2002) Enhanced Human Well-Being through Livestock and Natural Resource Management (East African Highlands), IDRC Research Project http://www.idrc.ca/en/ev-83043-201_003494-1-IDRC_ADM_INFO.html

Livestock in the East African Highlands provide food as well as income, fuel, and draught power but poor animal management has contributed to land degradation. Though a systems approach using an "agro-ecosystem health paradigm" this project determined which natural resource management could better lead to improved health for women, men and children.

Mearns R (1996) When Livestock are Good for the Environment: Benefit-sharing of Environmental Goods and Services World Bank/FAO Workshop, 'Balancing Livestock and the Environment', Washington, DC, September 27-28, 1996 (an associated event to the Fourth World Bank Conference on Environmentally Sustainable Development) ftp://ftp.fao.org/docrep/nonfao/LEAD/X6184e/X6184e00.pdf

Focusing principally on pastoral grazing and integrated crop- livestock systems, this paper examines the less widely documented case of positive environmental externalities associated with livestock production (e.g. enhancing soil fertility and nutrient cycling, supporting sustainable rangeland management, preserving wildlife and other forms of biodiversity).

Service MW (1991) Agricultural Development and Arthropod-borne Diseases: a Review *Rev Saude Publica* Jun; 25(3):165-78

Effects of deforestation, livestock development and irrigation on vector abundance and changing patterns of disease (malaria, trypanosomiasis, leishmaniasis, Chagas and arboviral infections) is presented. Whether livestock diverts biting away from people and reduces disease (zooprophylaxis) or whether cattle increases biting populations is discussed.

b) Wildlife

Acevedo-Whitehouse K, Duffus ALJ (2009) Effects of Environmental Change on Wildlife Health *Phil Trans R Soc B* 364, pp 3429–3438 doi:10.1098/rstb.2009.0128

The authors examine effects of rapidly changing environment on immune-competence of wildlife and levels at which anthropogenic environmental change affect wildlife health.

Massussi JA, et al. (2009) Influence of Habitat and Seasonal Variation on Wild Mammal Diversity and Distribution with Special Reference to the *Trypanosoma brucei gambiense* Host-reservoir in Bipindi (Cameroon) *Acta Tropica* Vol 112, Issue 3, pp 308-315 doi: 10.1016/j.actatropica.2009.08.027

The authors evaluated the role of wildlife in the resurgence and perenisation of human African trypanosomiasis considering habitat and seasonal variations in the diversity and spatial distribution of wild mammals (especially potential host-reservoirs in SW Cameroon) using transect surveys in four habitat types. Some species showed a slight density increase between the long dry and heavy rainy seasons within the undisturbed and farmland habitats, and a slight decrease within cocoa plantations and village-adjacent forests in the same period. Variations indicated a permanent movement of wild mammal reservoir or feeding hosts from one biotope to another over the seasons.

Faust C, et al. (2009) Filter-feeding Bivalves can Remove Avian Influenza Viruses from Water and Reduce Infectivity *Proc R Soc B* 276: pp 3727-3735

Avian influenza (AI) viruses are believed to be transmitted within wild aquatic bird populations through an indirect faecal–oral route involving contaminated water. This study examined the influence of filter-feeding bivalves (clams) on the infectivity of AI virus in water using wood ducks divided into various inoculated test groups. None of the wood ducks inoculated with AI-infected water filtered by clams or fed tissue from these clams exhibited morbidity or mortality. In contrast, all wood ducks exposed to either HPAI-infected water without clams or the original viral inoculum died. The findings reveal that filter-feeding bivalves can remove and reduce the infectivity of AI viruses in water.

Lloyd-Smith JO, et al. (2009) Epidemic Dynamics at the Human-Animal Interface *Science* 326, 1362 doi: 10.1126/science.1177345

Few infectious diseases are entirely human-specific. Most human pathogens also circulate in animals or originated in nonhuman hosts and this multi-host ecology of zoonoses leads to complex dynamics. Much attention has focused on modeling pathogens with relatively simple life cycles and immediate global urgency e.g., influenza, while vector-transmitted, chronic, and protozoan infections have been neglected - as have crucial processes such as cross-species transmission. Progress in understanding and combating zoonoses requires a new generation of models

that addresses a broader set of pathogen life histories and integrates across host species and scientific disciplines.

Rabinowitz P, Odofin L, Dein FJ (2008) From Us vs. Them to Shared Risk: Can Animals Help Link Environmental Factors to Human Health? *Ecohealth* Vol 5 Issue: 2 pp 224-9

Animals could be developed as models for environmentally-induced disease as well as potential "sentinels", providing early warning of both noninfectious and infectious hazards in the environment using a "shared risk" paradigm.

Jones KE, et al. (2008) Global Trends in Emerging Infectious Diseases *Nature* 451, 990-993 doi:10.1038/nature06536

The authors analyze a database of multiple EID 'events' and demonstrate non-random global patterns. Their results reveal a substantial risk of wildlife zoonotic and vector-borne EIDs originating at lower latitudes where reporting effort is low.

Hernández-Mora G, et al. (2008) Neurobrucellosis in stranded dolphins, Costa Rica *Emerg Infect Dis* http://www.cdc.gov/EID/content/14/9/1430.htm

Increased contact between cetaceans and humans has augmented the transmission risk of pathogenic brucellosis, a zoonosis of terrestrial and marine mammals, to people. This report documents the presence of marine brucellosis along Latin American shorelines and risk to people handling infected dolphins returning them to the ocean. Other stranded dolphins have been slaughtered as a food source for humans and domestic animals posing risk of zoonosis.

Hammill A, Giannikopoulos D, Karesh W (2007) SARS and Avian Influenza: Exploring the Role of Conservation and Veterinary Health in Addressing Zoonotic Diseases in Asia in Poverty Health and Ecosystems: Experience from Asia by Steele P, Oviedo G and McCauley D (eds) IUCN/ADB

Increased risk of transmission of zoonotic pathogens can be attributed to: increased contact between humans and animals, movement of people and farming into wildlife habitat, food habits and lack or breakdown of public health measures, among others. This case study examines causes and impacts of avian influenza and SARS in the Asia and Pacific region, demonstrating close connections between animal and human health.

Lebarbenchon C, et al. (2006) Parasitological Consequences of Overcrowding in Protected Areas *EcoHealth* Vol 3, No 4

The authors discuss parasitological consequences of animal over-crowding in protected wildlife areas, focusing on interactions between free living species and

parasite population dynamics, the evolution of parasite virulence, indirect effects on invertebrate community structure and the nutritional value of prey species.

Ostfeld RS, Holt RD (2004) Are Predators Good for your Health? Evaluating Evidence for Top-down Regulation of Zoonotic Disease Reservoirs *Front Ecol Environ* 2004; 2(1): 13–20 http://www.ecostudies.org/reprints/Ostfeld_and_Holt_2004_Front_Ecol_Environ_2_13-20.pdf

Many zoonotic disease agents are harbored in rodent populations and humans are victims of "accidental" transmission. The authors explore the idea that predatory vertebrates indirectly protect human health by reducing population size of rodent reservoirs of human disease.

Daszak P, Cunningham AA, Hyatt AD (2001) Anthropogenic Environmental Change and the Emergence of Infectious Diseases in Wildlife *Acta Tropica* Vol 78, Issue 2, 23 pp 103-116 doi: 10.1016/S0001-706X (00)00179-0

The authors highlight important wildlife EIDs that exemplify the varied etiology, pathogenesis, zoonotic potential and ecological impact of wildlife EIDs. Similar underlying factors drive disease emergence in both human and wildlife populations - predominantly ecological and almost entirely the product of human environmental change. Implications are twofold: emerging wildlife diseases cause direct and indirect loss of biodiversity and add to the threat of zoonotic disease emergence.

Daszak P, Cunningham AA, Hyatt AD (2000) Emerging Infectious Diseases of Wildlife-- Threats to Biodiversity and Human Health *Science* 21 Vol 287 No 5452 pp. 443 – 449

Many wildlife species are reservoirs of pathogens threatening domestic animals and human health. EIDs of free-living wild animals can be classified as (i) EIDs associated with "spill-over" from domestic animals to wildlife populations living in proximity; (ii) EIDs related directly to human intervention via host or parasite translocations; and (iii) EIDs with no overt human or domestic animal involvement.

Hahn BH, et al. (2000) AIDS as a Zoonosis: Scientific and Public Health Implications *Science* 28 Vol 287 No 5453 pp. 607-614

Evidence of simian immunodeficiency virus (SIV) infection has been reported for 26 different species of African nonhuman primates. Two are the cause of acquired immunodeficiency syndrome (AIDS) in humans and have been transmitted to humans on at least seven occasions. Implications of human infection by a diverse set of SIVs and of exposure to a plethora of additional human immunodeficiency virus-related viruses are discussed.

Wolfe ND, et al. (1998) Wild Primate Populations in Emerging Infectious Disease Research: The Missing Link? *Emerging Infectious Diseases* Vol 4 No 2

Wild primate populations may hold valuable clues to the origins and evolution of important pathogens as they can act as reservoirs for human pathogens. As members of biologically diverse habitats, they serve as sentinels for surveillance of emerging pathogens.

c) Parasites

Pascual S, González AF, Guerra A (2007) Parasite Recruitment and Oceanographic Regime: Evidence Suggesting a Relationship on a Global Scale *Biological Reviews* Vol 82 Issue 2**,** pp 257 – 263

The authors investigate the relationship between oceanographic processes and variability in parasite recruitment to host populations under differing hydrographic conditions. Exploited fish and cephalopod data reveal that variability in recruitment of parasite infra-communities is associated with major ocean current systems. Instability in water masses from physical perturbations (e.g. water mass convergence and turbulent mixing in upwelling systems) is associated with instability of trophic interactions over time, in turn leading to a paucity of parasite communities. The relationship between parasite recruitment and oceanographic regime may be useful as an indicator of ecosystem health.

Hudson PJ, Dobson AP, Lafferty KD (2006) Is a Healthy Ecosystem One that is Rich in Parasites? *Trends in Ecology & Evolution* Vol 21, Issue 7, pp 381-385 doi:10.1016/j.tree.2006.04.007

The role of parasites in ecosystem functioning has been trivialized because of relative low biomass compared with that of other trophic groups. Increasing evidence suggests parasite-mediated effects could be significant through shaping host population dynamics, altering inter-specific competition, influencing energy flow and acting as important drivers of biodiversity. They also have a major effect on the structure of some food webs.

Thomas F, Renaud F, Guégan JF (2005) (eds) Parasitism and Ecosystems, Oxford University Press

This book summarizes current knowledge on the dynamics of parasites in ecosystems and the diversity of ways in which they influence ecosystem functioning through their effects on host populations and communities.

III. What dimensions of human alteration matter most to the effects of environment on health?

Deforestation and associated environmental effects are the key dimensions described, similarly reflecting the emphasis on vector-borne disease. Increased human/wildlife

contact is another dimension directly associated with disease that is well described in the literature.

1) Conceptual frameworks and summary documents

Levy K, Daily GC, Myers SS (2010) Ecosystem Services & Human Health: A Conceptual Framework in Ingram JC, DeClerk F, Rumbaitis-del Rio C (eds) The Role of Ecology in Poverty Reduction, Edited Volume. In preparation for Springer Science and Business Media, LLC

The authors explore how ecosystem conditions and human health are directly linked to identify practical and reliable indicators of ecosystem condition / function that i) signal levels of risk to human health or ii) whether change in certain ecosystem attributes (size, configuration, composition) reliably translate into changes in health risks. Examples of adverse health impacts from deteriorating ecosystem services include i) how draining swamps reduces malaria mosquito vector habitat and ii) how ecosystems help purify and regulate drinking water flow for which substitutes are not available at the required scale. The authors also explain why epidemiological evidence for these relationships is difficult to establish.

Patz JA, et al. (2004) Unhealthy Landscapes: Policy Recommendations on Land Use Change and Infectious Disease Emergence *Environmental Health Perspectives* Vol 112, No 10

Anthropogenic land use changes (deforestation, wetland modification, coastal zone degradation, agricultural encroachment, roads and dams, mining, urban expansion/density, among others) drive infectious disease outbreaks and modify the transmission of endemic infections. These, in turn, cause a cascade of factors that exacerbate infectious disease emergence e.g., forest fragmentation, disease introduction, pollution, poverty, and human migration. A Working Group on Land Use Change and Disease Emergence established a systems model approach and priority lists of infectious diseases affected by ecologic degradation.

Chivian E (2001) Species Loss and Ecosystem Disruption: The Implications for Human Health *Canadian Medical Association Journal* 164:66-69

Degradation, reduction and fragmentation of habitats are the greatest threat to biodiversity loss, particularly in species-rich areas such as tropical rain forests and coral reefs. This article reviews ways that plant, animal and microbial species support human health and produce ecosystem services.

Patz JA, et al. (2000) Effects of Environmental Change on Emerging Parasitic Diseases *International Journal for Parasitology* Vol 30, Issues 12-13, pp 1395-1405

Deforestation and ensuing changes in land use, human settlement, commercial development, road construction, water control systems (dams, canals, irrigation systems, reservoirs), and climate, singly, and in combination have been accompanied by increases in morbidity and mortality from emergent parasitic disease. Replacement of forests with crop farming, ranching, and raising small animals can create supportive habitats for parasites and their host vectors. When the land use of deforested areas changes, human settlement patterns alter and habitat fragmentation may provide opportunities for exchange and transmission of parasites to previously uninfected humans. Construction of water control projects can lead to shifts in vector populations and their parasites; new roads in previously inaccessible forested areas can lead to erosion and stagnant ponds by blocking the flow of streams when water rises during the rains. The combined effects of environmentally detrimental changes in local land use and alterations in global climate disrupt natural ecosystems and can increase the risk of transmission of parasitic diseases to the human population.

World Resources Institute (1998) World Resources 1998-99: Environmental Change and Human Health. A joint publication by the World Resources Institute, the United Nations Environment Programme, the United Nations Development Programme, and The World Bank http://www.wri.org/publication/world-resources-1998-99-environmental-change-and-human-health

This publication explores the links between environmental quality and human health, describing how environmental conditions contribute to the current burden of death and disease around the world. It considers trends that are changing the physical environment with the potential to influence human health (e.g. intensification of agriculture, industrialization and rising energy use).

2) Deforestation

Vittor AY, et al. (2009) Linking Deforestation to Malaria in the Amazon: Characterization of the Breeding Habitat of the Principal Malaria Vector, *Anopheles darling Am J Trop Med Hyg* 81(1) pp. 5–12

This study examined larval breeding habitats of the malaria vector in areas with varying degrees of ecologic alteration in the Peruvian Amazon. Sites with larvae had approx 25% forest cover compared with 40% for sites without ($P < 0.0001$). Multivariate analysis identified the amount of forest and secondary growth, seasonality, algae, water body size and presence of human populations as significant determinants of vector presence. The authors conclude that deforestation and associated ecologic alterations are conducive to vector larval presence and thereby increase malaria risk.

O'Sullivan L, et al. (2008) Deforestation, Mosquitoes, and Ancient Rome: Lessons for Today *BioScience* Vol 58, No 8

Changes in vector density and distribution result from anthropogenic environmental changes and ecosystem disruptions, paramount among these being deforestation. It is the inevitable forerunner to agricultural development, irrigation and other associated water-resource developments such as dam construction. Soil salinization was recently added as a deforestation-associated mechanism with the potential to enhance vector mosquito breeding and thus increase vector borne disease transmission.

Chua KB, Chua BH, Wang CW (2007) Deforestation and the Nipah Virus in Malaysia in Poverty Health and Ecosystems: Experience from Asia by Steele P, Oviedo G and McCauley D (eds) IUCN/Asia Development Bank

In 1998, a novel paramyxovirus (Nipah) emerged in Malaysia killing domestic pigs and humans. Fruit bats are its natural reservoir host. Deforestation for pulpwood and industrial plantations has substantially reduced the forest habitat of these bats; and, slash-and-burn deforestation producing a severe haze directly preceded the outbreak. The fire was exacerbated by drought, driven by a severe ENSO event. This case study suggests that a series of events led to an acute reduction in the availability of flowering and fruiting forest trees for foraging by fruit bats, compelling them to migrate into cultivated fruit orchards. These anthropogenic events and the location of piggeries within orchards allowed the transmission of Nipah from its reservoir host to domestic pigs and, ultimately, to humans.

Vittor AY, et al. (2006) The Effect of Deforestation on the Human-biting Rate of *Anopheles darlingi*, the Primary Vector of Falciparum Malaria in the Peruvian Amazon *Am J Trop Med Hyg*, 74(1), 2006, pp. 3-11

The authors examine the impact of tropical rain-forest destruction in the Peruvian Amazon on malaria. They measured rates at which the primary vector fed on humans in areas with varying degrees of ecological alteration. Deforested sites had a biting rate more than 278 times higher than that for areas predominantly forested. The study revealed that the vector displays significantly increased human-biting activity in areas that have undergone deforestation and development associated with road development.

Vasconcelos PC, et al. (2001) Inadequate Management of Natural Ecosystem in the Brazilian Amazon Region Results in the Emergence and Reemergence of Arboviruses *Cad Saúde Pública* Vol 17, suppl

This paper analyzes the impact of vector and host population changes on various viruses in the Brazilian Amazon as a result of profound changes in the natural environment. Deforestation, mining, dam and highway construction, human colonization, and urbanization were the main manmade environmental changes associated with the emergence and/or reemergence of relevant arboviruses, including some known pathogens for humans.

Confalonieri U (2000) Environmental Change and Human Health in the Brazilian Amazon *Global Change & Human Health* Vol 1, No 2

Human intervention in Amazonian ecosystems has been followed by major negative environmental impacts, deforestation being the most important due to its large extension, rapid progress and global and multi-factorial consequences. All these processes are changing the region's disease profile- new diseases are emerging, others are being introduced and old ones are becoming out of control

Walsh JF, Molyneux DH, Birley MH (1993) Deforestation: Effects on Vector-borne Disease *Parasitology* 106 suppl: S55-75

This review addresses changes in the ecology of vectors of viral and parasitic infections and epidemiology of vector-borne diseases resulting directly and indirectly from deforestation. In South America and SE Asia deforestation has produced new habitats for mosquitoes and malaria epidemics. Species of sandflies (originally zoophilic and sylvatic) have adapted in SE Asia to feed on humans in peridomestic and even periurban situations. Studies on onchocerciasis have detected changes in its vector distribution in relation to changed habitats.

3) Habitat fragmentation

Gillespie TR, Chapman CA (2006) Prediction of Parasite Infection Dynamics in Primate Meta-populations based on Attributes of Forest Fragmentation *Conservation Biology* 20:441–448

The authors examine how fragment attributes affect potentially pathogenic gastrointestinal parasite infection dynamics in red colobus in western Uganda, and how changes affect host meta-populations. Physical (i.e., size, location, and topography) and biological (i.e., tree diversity, tree density, stump density, and colobine density) attributes were quantified for each fragment. Inter-fragment comparisons demonstrated that an index of degradation and human presence (tree stump density) strongly influenced the prevalence of parasitic nematodes. Infection risk was high where stump density was high. Results reveal that host-parasite dynamics can be altered in complex ways by forest fragmentation and that intensity of extraction (e.g., stump density) best explains the changes.

Allan BF, Keesing F, Ostfeld RS (2003) Effect of Forest Fragmentation on Lyme Disease Risk *Conservation Biology* Vol 17 Issue 1, pp 267 – 272

Forest fragmentation following destruction in the US reduces mammalian species diversity, elevating mice density in small fragments and increasing human exposure to Lyme disease. The authors show how small forest patches (<2 ha) with higher density of infected tick vectors is a key risk factor compared to larger patches (2–8 ha). They found a significant linear decline in infection prevalence and exponential decline in tick nyphmal density with increasing patch area. Decreasing forest patch size led to a dramatic increase in density of infected ticks

and therefore in Lyme disease risk. No similar relationship existed between tick larval density and patch size suggesting that by influencing community composition of vertebrate hosts for disease-bearing vectors, habitat fragmentation can influence human health.

4) Human/wildlife contact

Gillespie TR, Nunn CL, Leendertz FH (2008) Integrative Approaches to the Study of Primate Infectious Disease: Implications for Biodiversity Conservation and Global Health *Am J Phys Anthropol* suppl 47: 53-69.

The close phylogenetic relationship between humans and nonhuman primates, coupled with the exponential expansion of human activities within primate habitats, has resulted in exceptionally high potential for pathogen exchange with emerging infectious diseases as a consequence. This study examines how anthropogenic effects alter the zoonotic potential of various pathogenic organisms.

Rwego IB, et al. (2008) Gastrointestinal Bacterial Transmission among Humans, Mountain Gorillas, and Livestock in Bwindi Impenetrable National Park, Uganda *Conservation Biology* Vol 22 Issue 6, pp 1600 – 1607

The authors analyzed *E. coli* from humans, livestock, and mountain gorillas (*Gorilla gorilla beringei*) in Bwindi, Uganda to examine whether habitat overlap influences rates and patterns of pathogen transmission between humans and apes and whether livestock might facilitate transmission. Gorillas overlapping with people and livestock at high rates harbored *E. coli* genetically similar to that of people and livestock whereas *E. coli* from gorillas not overlapping in their use of habitats with people and livestock were more genetically distant. Isolates from all three species were clinically resistant to at least one antibiotic used by local people and the proportion of gorillas harboring resistant isolates declined in proportion to decreasing degrees of habitat overlap with humans. These patterns suggest that habitat overlap between species affects gastrointestinal bacterial transmission dynamics, perhaps through domestic animal intermediates and the physical environment.

Goldberg TL, et al. (2007) Patterns of Gastrointestinal Bacterial Exchange between Chimpanzees and Humans involved in Research and Tourism in Western Uganda *Biological Conservation* Vol 135, Issue 4, pp 511-517

Ecological overlap may increase risk of microbial exchange between humans and wild non-human primates. *E. coli* were collected from chimpanzees and humans in Kibale, Uganda to examine whether interaction between humans and apes in the wild might affect gastrointestinal bacterial communities in the two species. Chimpanzees harbored bacteria genetically more similar to those of humans involved in chimpanzee-directed research and tourism than to those of humans from a local village. Most humans (81.6%) and 4.4% of chimpanzees harbored at least one isolate resistant to locally available antibiotics. These data indicate that

humans and apes interacting in the wild can share genetically and phenotypically similar gastrointestinal bacteria, presumably originating from common environmental sources.

Chapman CA, Gillespie TR, Goldberg TL (2005) Primates and the Ecology of their Infectious Diseases: How will Anthropogenic Change Affect Host-Parasite Interactions? *Evolutionary Anthropology: Issues, News and Reviews* Vol 14 Issue 4: 134-44

Monkeys and apes often share parasites with humans. Understanding the ecology of infectious diseases in nonhuman primates is thus of paramount importance. This article describes how environmental change may promote contact between humans and nonhuman primates increasing the possibility of sharing infectious diseases detrimental to one species or the other, or both.

a) Bushmeat hunting and preparation

Wolfe ND, et al. (2005) Bushmeat Hunting, Deforestation, and Prediction of Emerging Infectious Diseases Zoonoses Emergence (perspective) *Emerging Infectious Diseases* Vol 11, No 12

The authors discuss an interdisciplinary approach that enables better understanding of how deforestation and associated hunting leads to the emergence of novel zoonotic pathogens.

Wolfe ND, et al. (2004) Naturally-acquired Simian Retrovirus Infections in Central African Hunters *The Lancet*, Vol 363, Issue 9413**,** pp 932 - 937

Hunting and butchering of wild non-human primates infected with simian immunodeficiency virus (SIV) is thought to have sparked the HIV pandemic. This study investigates zoonotic infection in individuals living in central Africa. Findings show that retroviruses are actively crossing into human populations and demonstrate that people in central Africa are currently infected with SFV. Contact with non-human primates, as happens during hunting and butchering, can play a part in the emergence of human retroviruses.

Brashares JS, et al. (2004) Bushmeat Hunting, Wildlife Declines, and Fish Supply in West Africa *Science* 12 Vol 306, No 5699, pp 1180 – 1183 doi: 10.1126/science.1102425

The authors reviewed years of data from Ghana to link mammal declines to the bushmeat trade and to spatial and temporal changes in the availability of fish. They showed that years of poor fish supply coincided with increased hunting in nature reserves and sharp declines in biomass of wildlife species.

b) Hunting in regrowth forests around agricultural lands

Wilkie DS (2005) Impact of Roadside Agriculture on Subsistence Hunting in the Ituri Forest of Northeastern Zaire *American Journal of Physical Anthropology* Vol 78, Issue 4, pp 485 - 494

Hunter capture records were used to assess if large areas of secondary forest surrounding roadside horticulturalists' settlements were successfully exploited for wild game, a primary protein source in the diet of local humans. Such forests within the Ituri region of Zaire are frequently and successfully exploited for wild game by subsistence hunters. Fauna exploited and capture weights were comparable between hunts in secondary and climax forest. This suggests that areas of regrowth forest surrounding horticulturalists' villages can and do provide substantial quantities of wild game for consumption by local inhabitants.

5) Human/Wildlife/Livestock interface

Mazet JAK, et al. (2009) A "One Health" Approach to Address Emerging Zoonoses: The HALI Project in Tanzania *PLoS Med* 6(12): e1000190 doi:10.1371/journal.pmed.1000190

Every day thousands die from under-diagnosed diseases that have arisen at the human–animal–environment interface, especially diarrheal and respiratory diseases in developing countries. Water resources in these countries are particularly crucial as humans and animals depend on safe water for health and survival, and sources of clean water are dwindling due to demands from agriculture and global climate change. Water scarcity means that people and animals use the same water sources for drinking and bathing which results in serious contamination of drinking water and increased risk of zoonotic diseases. The interconnectedness of human, animal, and environmental health is at the heart of One Health, an increasingly important prism through which governments, nongovernmental organizations, and practitioners view human health. The authors present an example of how this approach is being applied in a project in Tanzania.

Osofsky SA, et al. (2005) (eds) Conservation and Development Interventions at the Wildlife/Livestock Interface: Implications for Wildlife, Livestock and Human Health, IUCN, xxxiii and 220 pp

During a forum at the 2003 Vth IUCN World Parks Congress in South Africa, Wildlife Conservation Society (WCS) and the IUCN SSC Veterinary and Southern Africa Sustainable Use Specialist Groups (VSG and SASUSG) brought together many experts to develop ways to tackle health-related conservation and development challenges facing East and Southern Africa at the wildlife/domestic animal/human interface. This volume focuses on several important themes: competition over grazing and water resources, disease mitigation, local and global food security and other sources of conflict concerning land-use planning and resource constraints. This publication draws attention to the need to move towards a "one health" perspective – the foundation of the Durban discussions.

6) Agricultural expansion/intensification

Epstein JH, et al. (2006) Nipah Virus: Impact, Origins and Causes of Emergence *Current Infectious Disease Reports* Vol 8, No 1

Nipah causes severe febrile encephalitis and human case fatality of 40% to 75%. It emerged as a porcine neurologic and respiratory disease that spread to humans who had contact with live, infected pigs. Anthropogenic factors, including agricultural expansion and intensification, were underlying causes of its emergence.

Lindblade K, et al. (2000) Land Use Change Alters Malaria Transmission Parameters by Modifying Temperature in a Highland Area of Uganda *Tropical Medical Institute of Health* 5(4):263–274

Epidemics in highland areas of Africa historically free of malaria raise concern that high elevation malaria transmission is increasing. The authors investigated effects of land use change on malaria transmission in highlands of Uganda comparing mosquito density, biting rates, sporozoite rates and entomological inoculation rates between villages located along natural versus drained and cultivated swamps. As vegetation changes affect evapo-transpiration patterns and local climate, the authors also investigated differences in temperature, humidity and saturation deficit between natural and cultivated swamps. On average all malaria indices were higher near cultivated swamps although not statistically so. Village average minimum temperature was significantly associated with the number of vector mosquitoes/house suggesting that replacement of natural swamp vegetation with agricultural crops led to increased temperatures. This may have led to elevated malaria transmission risk in cultivated areas.

7) Dams

Behailu M, Haile M (2002) Water Harvesting in Northern Ethiopia: Environmental, Health and Socio-economic Impacts. Integrated Water and Land Management Research and Capacity Building Priorities for Ethiopia Workshop, International Livestock Research Institute http://www.ilri.org/publications/cdrom/integratedwater/iwmi/Documents/Papers/Mintesinot.htm

In northern Ethiopia, water scarcity is a key factor in food security. Small-scale irrigation using micro-dams improved food security in Tigray but negative impacts included soil salinity and erosion. Additionally, malaria has become a growing concern in micro-dam areas at lower altitudes. Both positive and negative impacts of micro-dam water harvesting systems need to be well understood before up-scaling.

8) Ranching

Herrera HM, et al. (2007) Variables that Modulate the Spatial Distribution of *Trypanosoma cruzi* and *Trypanosoma evansi* in the Brazilian Pantanal *Acta Tropica* Vol 102, Issue 1, pp 55-62 doi:10.1016/j.actatropica.2007.03

The authors evaluated how landscape and cattle ranching affect transmission cycles and patterns of *tripanosomatid* infection (two species) in small wild mammals in the Pantanal - a large natural environment with many habitats and a wide variety of biodiversity as well as livestock - comparing one preserved and one cattle ranching area. The role of small mammals in the transmission cycle of both trypanosomes species was distinct according to land use. The study showed that cattle ranching in the study area did not enhance overall prevalence of *T. cruzi* infection among small wild mammals. Small mammal fauna diversity was the same but relative abundance differed suggesting that ranching activity may not necessarily result in biodiversity loss or risk of Chagas disease.

IV. What attributes of the (biotic) environment affect health?

This section reviews evidence on dimensions of biodiversity that matter to human health: species diversity, ecological intactness, ecosystem type and geographic location. A few key references are included on the effects of climate change on health.

Rapport DJ, et al. (2009) The Impact of Anthropogenic Environmental Change at Global and Regional Scales on Biodiversity and Human Health Chapter in Biodiversity Change and Human Health: From Ecosystem Services to Spread of Disease by Sala OE, Meyerson LA, Parmesan C (eds), Island Press

Links between levels of anthropogenic environmental change and human health are well known, particularly with reference to emerging infectious diseases. The role of biodiversity in determining human health is less understood. Levels and layers of complexity are the rule rather than the exception in describing the relationships between biodiversity, the environment, and human health. Socioeconomic and cultural dimensions are critical to this understanding.

Chapin FS, et al. (2008) Disease Effects on Landscape and Regional Systems: A Resilience Framework Chapter 13 in Infectious Disease Ecology: The Effects of Ecosystem on Disease and of Disease on Ecosystems by Ostfeld RS, Keesing F, Eviner VT (eds), Princeton University Press

Disease epidemics are disturbances that alter interactions among ecological and social components of regional systems. The ecological impacts of disease are largely mediated by changes in dominant and keystone plant species or in animals that regulate these plant species - loss of which generally increases the flux of water and nutrients among patches on a landscape, increasing landscape connectivity. Diseases have the potential to affect all pathways of interactions among patches on the landscape but their impacts on disturbance regimes have the largest long-term consequences, sometimes leading to changes in ecosystem state. Resilience theory provides a framework for predicting, preparing for and managing the consequences of profound state changes.

McCallum H (2008) Landscape Structure, Disturbance and Disease Dynamics Chapter 5 in Infectious Disease Ecology: The Effects of Ecosystem on Disease and of Disease on Ecosystems by Ostfeld RS, Keesing F and Eviner VT (eds), Princeton University Press

Landscape structure influences population density and movement patterns of hosts, vectors and transmission stages and thereby also infectious disease dynamics. In a spatial context, an infected host is more likely to be near another infected host than is the case in a homogeneous mixing system. Understanding landscape is also critical in predicting the quantitative spread of infectious disease because landscape features can serve as either barriers or conducts to disease spread. For example, anthropogenic landscape changes, in particular habitat destruction and fragmentation, have lead to disease emergence in a number of situations. However, most classic infectious disease models do not include any spatial structure. The author notes how no general conclusions can be drawn about the influence of meta-population parameters (e.g. patch size and isolation) on disease dynamics and discusses how landscape manipulation can be used to manage pathogen threats.

Pongsiri MJ,Roman J (2007) Examining the Links between Biodiversity and Human Health: An Interdisciplinary Research Initiative at the US Environmental Protection Agency *EcoHealth* doi: 10.1007/s10393-007-0087-3

Under the US Environmental Protection Agency's (EPA) mission to protect human health and the environment, the agency seeks to conduct research on the structure and function of ecosystems and to improve our understanding of the processes that contribute to the sustained health of the nation's ecosystems and the well-being of human populations. Changes in biodiversity can profoundly impact the ability of ecosystems to provide clean water, energy, food, recreation, and other services that contribute to human well-being. In addition, changes in biodiversity can affect the transmission of infectious disease to humans, particularly vector-borne diseases such as malaria and Lyme disease. The EPA's new initiative supports interdisciplinary research to characterize the mechanisms that link biodiversity and human health and to use this knowledge to develop integrative tools and approaches for quantifying and predicting these relationships.

Rapport DJ (2006) Sustainability Science: An Ecohealth Perspective *Sustain Sci* doi: 10.1007/s11625-006-0016-3

Sustainability science is emerging as a trans-disciplinary effort to address the symbiosis between human activity and the environment. There is clear evidence that the Earth's ecosystems and landscapes continue to degrade as a consequence of the cumulative impact of human activities. Taking an ecohealth approach to sustainability science provides a unique perspective on both the goals and the means to achieve sustainability. Achieving ecosystem health should become the cornerstone of sustainability policy—for healthy ecosystems are the essential

precondition for achieving sustainable livelihoods, human health, and many other societal objectives, as reflected in the Millennium Development Goals.

Folke C, et al. (2004) Regime Shifts, Resilience and Biodiversity in Ecosystem Management *Annual Review of Ecology, Evolution and Systematics* Vol 35 pp 557-581 doi:10.1146/annurev.ecolsys.35.021103.105711

The authors review the evidence on regime shifts in terrestrial and aquatic environments in relation to complex adaptive ecosystem resilience and the functional roles of biological diversity. The findings reveal an increased likelihood of regime shifts with reduced resilience due to human actions that: remove response diversity, whole functional groups of species, or whole trophic levels; impact on ecosystems via emissions of waste and pollutants and climate change; or, alter the magnitude, frequency, and duration of disturbance regimes. Such pressures can make ecosystems more vulnerable to changes that previously could be absorbed and less capable of generating ecosystem services.

Kochtcheeva L, Singh A (2000) An Assessment of Risks and Threats to Human Health Associated with the Degradation of Ecosystems, UNEP/DEIA&EW/TR 00-5 http://na.unep.net/publications/heireport.pdf

Many threats to human health are an intrinsic part of ecosystems. Ecosystems that are sufficiently stable and biologically diverse tend to maintain the quality of human health. On the other hand, degraded or collapsed ecosystems seem to have a significant impact on human health. Changes in the distribution and ecological activity of organisms, often resulting from environmental modifications, may give early evidence of environment-related shifts in human health risks. In many cases, disease appearances are symptoms of ecosystem dysfunction. Three fundamental mechanisms and forms of ecosystem degradation affecting human health were identified: • Indirect depletion of ecological systems (soil degradation, water supplies degradation, biogeochemical cycles alterations, climate change, ozone layer depletion, and water, air and soil pollution; • Direct depletion of non-human living systems (loss of biodiversity, renewable resources exhaustion, pest outbreaks, spread of alien species); • Direct depletion of human systems (epidemics, emerging and re-emerging diseases, and reduced quality of life).

Indices of the sustainability of health status should focus on the integrity and stability of the global ecological systems that maintain the life and health of the population. Such indices would not directly measure human biology but rather the degree to which human biophysical needs are being satisfied by the sustainable use of ecosystem services. The indicators could include bio-indices predictive of human disease risk e.g., the degree of balance between population size and available resources or vegetation cover and groundwater levels in relation to infectious disease transmission.

1) Factors affecting infectious disease

Myers SS (2009) Land Use and Human Health in Ingram JC, DeClerk F, Rumbaitis-del Rio C (eds) The Role of Ecology in Poverty Reduction, Edited Volume. In preparation for Springer Science and Business Media, LLC

Pervasive landscape changes include deforestation, extension and intensification of agriculture, and livestock management, the construction of dams, irrigation projects, and roads, and rapidly spreading urbanization. Each change has important health implications including the emergence of new infectious diseases and altered distribution of recognized diseases. Mechanisms by which land use change may alter exposure to infectious disease include alteration of: 1) biophysical conditions of habitats that can affect the *density or presence of disease-related organisms*; 2) *exposure pathways*, or the way organisms (including humans) interact with each other; 3) the *genetics* of pathogens; 4) the *life cycles* of pathogens and vectors; and 5) *species composition* within a community of organisms. Infectious diseases transmitted by a vector (usually an arthropod), or that have a non-human host or reservoir are particularly sensitive to these changes. Such diseases affect over half the human population, particularly the poor.

Keesing F, et al. (2009) Hosts as Ecological Traps for the Vector of Lyme disease *Proc R Soc B* doi: 10.1098/rspb.2009.1159

Vectors of infectious diseases are generally thought to be regulated by abiotic conditions such as climate or the availability of specific hosts or habitats. In this study, the authors subjected field-caught vertebrate hosts to parasitism by larval blacklegged ticks, the vectors of Lyme disease, and found that some host species that are abundantly parasitized in nature kill most (up to 96%) of ticks that attempt to attach and feed while other species are more permissive of tick feeding. They also show that some hosts can kill thousands of ticks per hectare, revealing that the abundance of tick vectors can be regulated by the identity of the hosts upon which these vectors feed. Using empirical models and simulating the removal of hosts from intact communities, the authors show that biodiversity loss may exacerbate disease risk by increasing both vector numbers and vector infection rates with a zoonotic pathogen.

Pongsiri MJ, et al. (2009) Biodiversity Loss Affects Global Disease Ecology *BioScience* 59: 945–954

Changes in the type and prevalence of human diseases have occurred during shifts in human social organization (e.g. from hunting and gathering to agriculture). The recent (re)emergence of infectious diseases however appears to be driven by globalization and ecological disruption. The authors propose that habitat destruction and biodiversity loss associated with biotic homogenization can increase the incidence and distribution of infectious diseases affecting humans. The clearest connection between biotic homogenization and infectious disease is the spread of non-indigenous vectors and pathogens. The loss of predators and hosts that dilute pathogen transmission can also increase the incidence of vector-borne illnesses. Other mechanisms include enhanced abiotic

conditions for pathogens and vectors and higher host-pathogen encounter rates. Improved understanding of these causal mechanisms can inform decision-making on biodiversity conservation as an effective way to protect human health.

Pulliam JRC (2008) Viral Host Jumps: Moving toward a Predictive Framework *EcoHealth* 5, pp 80–91 doi: 10.1007/s10393-007-0149-6

To help predict pathogen emergence in new host species, the author outlines a framework with molecular characteristics that ranks virus families by their expected a priori ability to complete three steps in the emergence process (encounter, infection, and propagation). Expected patterns (based on molecular-level structural characteristics) compare with empirical observations regarding the ability of specific viral families to infect novel host species. However, other factors e.g. the ecology of host interactions, determinants of cellular susceptibility and permissivity to specific virus groups need to be considered when trying to predict the frequency with which a virus will encounter a novel host species or the probability of propagation within a novel host species, once infection has occurred.

a) Host species diversity

Suzan G, et al. (2009) Experimental Evidence for Reduced Rodent Diversity Causing Increased Hantavirus Prevalence *PLoS ONE* 4(5): e5461. doi:10.1371/journal.pone.0005461

Increased disease incidence has been correlated with biodiversity loss for several zoonoses but experimental tests are lacking. The authors manipulated small-mammal biodiversity in a study in Panama where zoonotic hantaviruses are endemic. Both hantavirus prevalence in wild reservoir (rodent) populations and reservoir population density increased where small-mammal species diversity was reduced, supporting the conclusion that high biodiversity is important in reducing transmission of zoonotic pathogens among wildlife hosts.

Keesing F, Holt RD, Ostfeld RS (2006) Effects of Species Diversity on Disease Risk *Ecology Letters* 9: 485–498

Models and the literature suggest that high host diversity is more likely to decrease than increase infectious disease risk. This is especially likely when pathogen transmission is frequency-dependent and greater within species than between species, particularly when the most competent hosts are also relatively abundant and widespread.

Dobson A, et al. (2006) Sacred Cows and Sympathetic Squirrels: The Importance of Biological Diversity to Human Health *PLoS Med* 3(6): e231 doi:10.1371/journal.pmed.0030231

The authors describe how disease risk is influenced by biological diversity and how some (inefficient) host species act to reduce the risk of transmission of

virulent zoonotic pathogens to people. For example, cows and squirrels both receive bites from infected vectors that might otherwise have bitten humans thus breaking the chain of pathogen transmission (i.e., for Indian cattle, bites from malaria-infected mosquitoes and for squirrels from Lyme disease-infected ticks).

Woolhouse MEJ, Gowtage-Sequeria S (2005) Host Range and Emerging and Reemerging Pathogens *Emerging Infectious Diseases* Vol 11, No 12 www.cdc.gov/eid

Emerging and reemerging pathogens are not strongly associated with particular types of nonhuman hosts but most likely have the broadest host ranges. EID zoonoses are associated with a wide range of drivers. The most commonly cited ones are changes in land use and agriculture as well as demographic and societal change. While these zoonotic pathogens represent the most likely source of EIDs, only a small minority have proved capable of causing major epidemics in the human population.

b) Host species diversity and reservoir competence

Ostfeld RS, Keesing F (2000) The Function of Biodiversity in the Ecology of Vector-borne Zoonotic Diseases *Can J Zool* 78:2061-2078

This article describes how a diverse assemblage of vertebrates can dilute the impact of the principal reservoir of Lyme disease, thereby reducing disease risk to humans. Four conditions dictate whether the effect applies generally to vector-borne zoonoses: (1) feeding habits of the vector are generalized; (2) the pathogen is acquired by the vector from hosts (versus exclusively transovarially); (3) reservoir competence (i.e., ability of a host species to infect a vector) varies among host species; and (4) the most competent reservoir host tends to be a community dominant (i.e., the % of the tick population fed by that species). Under these conditions, vertebrate communities with high species diversity will contain a greater proportion of incompetent reservoir hosts deflecting vector meals away from the most competent reservoirs, thereby reducing infection prevalence and disease risk.

i) Lyme disease

Schmidt KA, Ostfeld RS (2001) Biodiversity and the Dilution Effect in Disease Ecology *Ecology* 82(3), pp. 609–619

Through computer simulations the authors explore a conceptual model (dilution effect) whereby the presence of vertebrate hosts with low capacity to infect feeding vectors (incompetent reservoirs) dilutes the effect of highly competent reservoirs, thus reducing disease risk using Lyme disease as an example. Increasing species richness reduces disease risk, the effects being most pronounced when the most competent disease reservoirs are community

dominants and when alternative hosts have a net negative influence on the dominant host animal.

LoGiudice K, et al. (2003) The Ecology of Infectious Disease: Effects of Host Diversity and Community Composition on Lyme Disease Risk *Proc Natl Acad Sci* 100: 567–571

The authors tested a model predicting that high species diversity in tick hosts reduces vector infection prevalence by diluting the effects of the most competent disease reservoir (mice). As habitats are degraded by fragmentation or other anthropogenic forces, some of the host community disappears, yielding species-poor communities with mice but few other hosts. As relatively poor reservoirs for the Lyme pathogen the latter reduce disease prevalence by feeding but rarely infecting ticks. The authors identify important "dilution hosts" (e.g., squirrels), characterized by high tick burdens, low reservoir competence and high population density, as well as "rescue hosts" (e.g., shrews), capable of maintaining high disease risk even when mouse density is low.

ii) West Nile

Allan BF, et al. (2008) Ecological Correlates of Risk and Incidence of West Nile Virus in the United States *Oecologia* 22

Several bird species appear to be the primary reservoir of West Nile virus whereas other birds, and other vertebrate species, can be infected but are less competent reservoirs. The authors found that the prevalence of West Nile virus infection in mosquito vectors and humans increased with decreasing bird diversity and with increasing reservoir competence of the bird community, possibly operating because high-diversity bird communities have lower community-competence. The findings suggest that conservation of avian diversity might help ameliorate the current West Nile virus epidemic in the US.

c) Host species diversity

Hechinger RF, Lafferty KD (2005) Host Diversity Begets Parasite Diversity: Bird Final Hosts and Trematodes in Snail Intermediate Hosts *Proc Biol Sci* 272 (1567): 1059–1066 http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1599879

Biodiversity rich communities may foster parasitism. Few studies have directly tested whether for parasites sequentially using different host species throughout complex life cycles, parasite diversity and abundance in 'downstream' hosts increase with the diversity and abundance of 'upstream' hosts (which carry the preceding stages of parasites). The authors quantify birds at fine spatial scales, relating bird communities to larval trematodes in snails sampled at the same spatial scale. Species richness, species heterogeneity and abundance of final host birds were positively correlated with species richness, species heterogeneity and abundance of trematodes in host snails.

Guernier V, Hochberg ME, Guégan JF (2004) Ecology Drives the Worldwide Distribution of Human Diseases *PLoS Biol* 2(6): e141

Using generalized linear multivariate models and Monte Carlo simulations, the authors showed a significant negative relationship between latitude and parasitic and infectious disease (PID) species richness and a nested spatial organization, i.e., the accumulation of PID species with latitude over large spatial scales. Results reveal climatic factors primarily explain the link between latitude and the spatial pattern of human pathogens. Global latitudinal species diversity gradient therefore might be generated by biotic interactions.

d) Parasites

Kuris AM, et al. (2008) Ecosystem Energetic Implications of Parasite and Free-living Biomass in Three Estuaries *Nature* 454: 515-518

Parasites can have strong impacts but are thought to contribute little biomass to ecosystems. The authors quantified the biomass of free-living and parasitic species in three estuaries on the Pacific coast of California and Baja California and revealed that parasites have substantial biomass in those ecosystems, exceeding that of top predators. The biomass of trematodes was particularly high. Trophically-transmitted parasites and parasitic castrators subsumed more biomass than did other parasitic functional groups. The annual production of free-swimming trematode transmission stages was greater than the combined biomass of all quantified parasites and was also greater than bird biomass. This biomass and productivity of parasites implies a profound role for infectious processes in these estuaries.

e) Sequence of species loss

Ostfeld RS, Logiudice K (2003) Community Disassembly, Biodiversity Loss, and the Erosion of an Ecosystem Service *Ecology,* 84(6), 2003, pp. 1421–1427

The authors used an empirically-based simulation model to assess how the sequence of species loss from vertebrate communities influences risk of human exposure to Lyme disease (measured as the % of infected ticks). Randomized sequences of species loss resulted in a decrease in disease risk with reduced biodiversity, contradicting results from nonrandomized sequences of species loss (i.e., ‘‘disassembly rules’’). Analysis of all potentially realistic disassembly rules increased disease risk with decreasing biodiversity. Findings highlight the importance of species identity and the order by which species are lost in understanding mechanisms by which biodiversity affects ecosystem functioning.

f) Pathogen characteristics

Eviner VT, Likens GE (2008) Effects of Pathogens on Terrestrial Ecosystem Function Chapter 12 in Infectious Disease Ecology: The Effects of Ecosystem on

Disease and of Disease on Ecosystems by Ostfeld RS, Keesing F, Eviner VT (eds), Princeton University Press

Various studies have demonstrated that pathogens can strongly affect the performance of individual organisms, population dynamics and community interactions. Others suggest that pathogens can alter a wide range of ecosystem functions in terrestrial systems. However, a framework is lacking to predict the type and magnitude of ecosystem effects that a given pathogen will have. Based on the fields of disturbance ecology and ecosystem effects of species composition, the authors present a number of general principles determining how pathogens influence ecosystems over time. They focus on pathogens as drivers of ecosystem processes as well as on pathogens as disturbances.

Cleaveland S, Laurenson MK, Taylor LT (2001) Diseases of Humans and their Domestic Mammals: Pathogen Characteristics, Host Range and the Risk of Emergence *Phil Trans R Soc Lond B* 29 Vol 356, No 1411, pp 991-999

Pathogen characteristics, host range and risk factors for disease emergence were analyzed for pathogens affecting humans, domestic animals and wildlife. Multi-host pathogens were very prevalent among both human and domestic mammal pathogens. Across all hosts, helminths and fungi were relatively unlikely to emerge whereas viruses, particularly RNA virus, were highly likely to emerge. The ability of a pathogen to infect multiple hosts, particularly hosts in other taxonomic orders or wildlife, were risk factors for emergence in human and livestock pathogens.

g) Changing nitrogen cycles

McKenzie VJ, Townsend AR (2007) Parasitic and Infectious Disease Responses to Changing Global Nutrient Cycles *Ecohealth* Vol 4, No 4

This article explores how rapid changes in the nitrogen (N) cycle of tropical regions combined with high human PID diversity in these regions will markedly increase the potential for N to alter disease dynamics. Evidence suggests that higher nutrient levels lead to an increased risk of disease across multiple pathogen types (including helminths, insect-vectored diseases, myxozoa, and bacterial and fungal diseases). Effects are frequently indirect, regulated by intermediate or vector hosts involved in disease transmission.

h) Changes in predation

Holt, RD (2008) The Community Context of Disease Emergence: Could Changes in Predation be a Key Driver? Chapter 15 in Infectious Disease Ecology: The Effects of Ecosystem on Disease and of Disease on Ecosystems by Ostfeld RS, Keesing F, Eviner VT (eds), Princeton University Press

All host-pathogen interactions play out against a background of other ecological drivers and the web of interactions in local communities. Parasites can infect multiple host species and most host species are subject to infection by multiple parasites. In many natural systems, top predators are key species that profoundly govern system persistence and stability. Predators can affect host-pathogen interactions by acting as mortality factors or by facilitating disease transmission. Environmental change alters this background of species interactions and thus can indirectly modify host-pathogen dynamics in a variety of directions. Anthropogenic impacts can alter the abundance, behavior and even the existence of top predators. The author discusses several theoretical examples to illustrate expected effects in anthropogenically-modified ecosystems.

i) Ecotones

Despommier D, Ellis BR, Wilcox BA (2007) The Role of Ecotones in Emerging Infectious Diseases *EcoHealth* 3: 281–289

Research on emerging infectious diseases (EIDs) and the causes of increased rates of pathogen transmission, spread, and adaptation suggests a correspondence between ecotonal processes and the ecological and evolutionary processes responsible for zoonotic and vector-borne emerging infections. In reviewing the literature, the authors note that ecotones play a role in a number of the most important EIDs. The fact that about half of the approximately 130 zoonotic EIDs have similar disease ecologies suggests that EIDs and their increasing global trend may be generally associated with ecotones.

2) Climate change

TEEB (2009) TEEB Climate Issues Update http://www.teebweb.org/InformationMaterial/TEEBReports/tabid/1278/language/en-US/Default.aspx

This report assesses the economic magnitude of the human welfare impacts of losing natural areas. The authors describe in economic terms the fundamental links between eliminating poverty and conserving biodiversity and ecosystems. In preparation for the December 2009 negotiations in Copenhagen, this report presents a sub-set of early conclusions which relate to climate change and economics with recommendations for policy-makers, negotiators, and the general public. Three potential watershed issues are covered: • the imminent loss of *coral reefs* due to climate change with all the serious ecological, social, and economic consequences this will entail. • Forests perform a valuable function in capturing and storing carbon. An early and appropriate agreement on *forest carbon* would be a significant opportunity to mitigate climate change. It would also set the stage for related mechanisms to reward other ecosystem services from forests. • There is a compelling cost-benefit case for public investment in *ecological infrastructure* (especially restoring and conserving forests, mangroves, river basins, wetlands, etc.), particularly because of its significant potential as a means of adaptation to climate change.

Pacala S, Socolow R (2004) Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies *Science* 13: 968-972 doi: 10.1126/science.1100103

The authors present the case that humanity possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century. That is, technologies exist to meet the world's energy needs over the next 50 years and limit atmospheric CO2 to a trajectory that avoids a doubling of the pre-industrial concentration. They identify a set of options with the capacity to provide the seven stabilization wedges and solve the climate problem for the next half-century. Every one of these options they argue is already implemented at an industrial scale and could be scaled up further over 50 years to provide at least one wedge. And, while no single element can do the entire job, the overall portfolio is large enough that not every element has to be used.

a) Climate change and infectious disease

A subgroup of the substantial literature on climate change effects on infectious disease appears below. Effects operate principally through temperature and precipitation effects on vector biology.

Lafferty KD (2009) The Ecology of Climate Change and Infectious Diseases *Ecology* Vol 90, No 4, pp 888-900

Latitudinal, altitudinal, seasonal, and inter-annual associations between climate and disease suggest that climate can affect infectious diseases in a nonlinear fashion. Little evidence however documents that climate change has already favored infectious diseases. Initial projections suggested dramatic future increases in the geographic range of infectious diseases while recent models predict range shifts in disease distributions with little net increase in area. Many factors can affect infectious disease and some may overshadow the effects of climate.

Relman DA, et al. (2008) (rapporteurs) Global Climate Change and Extreme Weather Events: Understanding the Contributions to Infectious Disease Emergence (Workshop Summary Forum on Global Health), Institute of Medicine http://www.iom.edu/CMS/3783/3924/45653.aspx

Increased atmospheric and surface temperatures contribute to the worldwide burden of disease and premature deaths and are anticipated to influence transmission dynamics and the geographic distribution of malaria, dengue fever, tick-borne diseases, and diarrheal diseases such as cholera.

Epstein PR (2005) Climate Change and Human Health *New England Journal of Medicine* Vol 353, No 14, pp 1433-1436 http://www.countercurrents.org/cc-epstein081005.htm

Changes in biodiversity, altering the balance among predators, competitors, and prey that help keep pests and pathogens in check, have contributed to the resurgence of infectious diseases. While deforestation and fossil fuel combustion are major anthropogenic causes of climate change, even subtle, gradual climatic changes can damage human health. Temperature constrains the range of microbes and vectors (including mosquitoes) and weather affects the timing and intensity of disease outbreaks. For example, disease clusters frequently follow floods and prolonged drought can weaken trees' defenses against infestations and promote wildfires (that cause injuries, burns, respiratory illness, and deaths). A still greater threat to human health comes from illnesses affecting wildlife, livestock, crops, forests, and marine organisms.

Chivian E, Bernstein A (2004) Guest Editorial, Embedded in Nature: Human Health and Biodiversity *Environmental Health Perspectives* 112:A12-A13

Today, human practices, widening social inequities and changes in ecologic systems and climate are compounding and conspiring to unleash a barrage of emerging diseases that afflict humans, livestock, wildlife, marine organisms, and the very habitat upon which we depend. As the climate becomes more unstable, its role increases.

McMichael AJ, et al. (2003) (eds) Climate Change and Human Health: Risks and Responses, World Health Organization http://www.who.int/globalchange/climate/summary/en/index.html

Personal health is affected by behavior, heredity, occupation, local environmental exposures and health-care access. Sustained *population* health requires the life-supporting "services" of the biosphere. The world's climate system is fundamental to this life-support. Increase in infectious disease reflect the combined impacts of rapid demographic, environmental, social, technological and other changes in our ways-of-living as well as climate change.

Reiter P (2001) Climate Change and Mosquito-borne Disease *Environ Health Perspect* 109 (suppl 1): 141–161

Elementary models suggest that higher global temperatures will enhance mosquito-borne disease transmission rates and extend their geographic ranges. However, malaria, yellow fever, and dengue histories reveal that climate has rarely been the principal determinant of their prevalence or range. Human activities and their impact on local ecology have generally been much more significant. It is therefore inappropriate to use climate-based models to predict future prevalence of these diseases.

Githeko AK, et al. (2000) Climate Change and Vector-borne Diseases: a Regional Analysis *Bull World Health Organ* Vol 78, No 9

Malaria and dengue fever are important vector-borne diseases in the tropics and subtropics. Lyme disease is the most common vector-borne disease in the USA and Europe. Encephalitis is also becoming a public health concern. The greatest effect of climate change on transmission will likely be observed at the extremes of the range of temperatures at which transmission occurs. Different human settlement patterns and health infrastructures will also influence disease trends between countries.

Epstein PR (1997) Climate, Ecology, and Human Health *Consequences* Vol 3, No 2

Environmental conditions, interacting with the biology of disease agents, can exert profound effects on health. Changes in how land is used affect the distribution of disease carriers, such as rodents or insects, while climate influences their range, and affects the timing and intensity of outbreaks. In this review we examine how our health is influenced by the interplay of social conditions, local environmental factors, and global changes.

b) Climate change and other health effects

Patz JA, et al. (2005) Impact of Regional Climate Change on Human Health *Nature* 438:310-317

Human disease linked to climate fluctuations range from cardiovascular mortality and respiratory illnesses due to heat waves, to altered transmission of infectious diseases, to malnutrition from crop failures. Potentially vulnerable regions include: the temperate latitudes projected to warm disproportionately, areas around the Pacific and Indian oceans currently subjected to large rainfall variability (due to the ENSO) and, sprawling cities where the urban heat island effect could intensify extreme climatic events.

Patz JA (2002) A Human Disease Indicator for the Effects of Recent Global Climate Change *Proc Natl Acad Sci* 99:12506-12508

With new concerns about global warming, accompanied by greater climate variability, recent studies have focused on disease fluctuations related to short-term or inter-annual climate oscillations (e.g., from weather extremes driven by El Niño). The question remains as to whether or not there has been any documented change in human disease trends in response to long-term climate change, since warming has already occurred over the last century. This study provides evidence that warming trends over the last century are affecting human disease.

3) Habitat matrix quality

Franklin JF, Lindenmayer DB (2009) Importance of Matrix Habitats in Maintaining Biological Diversity *PNAS* Vol 106, No 2, pp 349-350 doi: 10.1073/pnas.0812016105

In the classic patch-matrix (or island) model of landscape cover, habitat patches are defined from a human perspective and the matrix is considered nonhabitat. Alternative conceptual models of landscapes often better predict species responses to landscape change and in identifying what constitutes suitable habitat (e.g. hierarchical patch dynamics, landscape variegation and species-specific gradient models).

Prugh LR, et al. (2008) Effect of Habitat Area and Isolation on Fragmented Animal Populations *Proc Natl Acad Sci 105:20770–20775*

The authors compile occupancy data from numerous animal populations on 6 continents to show that patch area and isolation are poor predictors of occupancy for most species. They examine improper scaling and species biases and potential explanations and find that land cover type separating patches most strongly affects the sensitivity of species to patch area and isolation. Their results indicate that patch area and isolation are indeed important factors affecting the occupancy of many species but that properties of the intervening matrix also matter. Improving matrix quality may lead to higher conservation returns than manipulating the size and configuration of remnant patches for many of the species that persist in the aftermath of habitat destruction.

4) Ecosystem type

a) Forest

Karjalainen E, Sarjala T, Raitio H (2009) Promoting Human Health through Forests: Overview and Major Challenges *Environmental Health and Preventive Medicine (*special feature)

This review looks at key health benefits forests provide and risks forests pose to human health. Forest food offers a safety net for the most vulnerable population groups in developing countries; healthy forest ecosystems also help in regulation of infectious diseases; forests represent rich natural pharmacies and promote physical and mental health by reducing stress. Utilizing forests effectively in health promotion could reduce public health care budgets and create new sources of income. Delivering health through forests is challenged by ecosystem and biodiversity degradation, deforestation, and climate change.

Guidotti TL, et al. (2008) An Agenda for Studying Human and Ecosystem Health in the Boreal Forest *Ecosystem Health* Vol 3 Issue 1, pp 11 – 26

The Network of Centres of Excellence (NCE) in Sustainable Forestry Management, a new research initiative in Canada, examines management

practices that protect boreal forest resources in western and northern regions while permitting controlled economic development. A critical factor is socioeconomic and cultural acceptability in local communities (generally small, remote, limited in economic resources and supporting a mixed economic development and traditional aboriginal activities). Health is an essential factor to sustainability. Health/ecosystem interactions may have direct health effects on the human body or work indirectly, mediated by social mechanisms.

Colfer CJP, Sheil D, Kishi M (2006) Forests and Human Health: Assessing the Evidence CIFOR Occasional Paper No. 45

This study focuses on the state of human health in forests and causal links between the two considering four issues: i) the forest as a food-producing habitat, human dependence on forest foods, the nutritional contributions of such foods, and nutrition-related problems affecting forest peoples, ii) tropical diseases and forest-related health problems, iii) benefits of forest medicines and iv) cultural interpretations of human health among forest peoples.

Balick MJ, Elisabetsky E, Laird SA (1996) Medicinal Resources of the Tropical Forest: Biodiversity and Its Importance to Human Health, Columbia University Press

WHO estimates that 80% of developing country people rely on harvested wild plants for part of their primary health care. This book discusses the potential impact of the destruction of the earth's rainforest in terms of human health for both developing and developed world inhabitants.

b) Wetlands

Olson SH, et al. (2009) Links between Climate, Malaria, and Wetlands in the Amazon Basin *Journal of Emerging Infectious Diseases* 15(4): 659-662

Climate changes are altering patterns of temperature and precipitation, potentially affecting regions of malaria transmission. The authors show that areas of the Amazon Basin with few wetlands show a variable relationship between precipitation and malaria incidence, while areas with extensive wetlands show a negative relationship.

Russell RC (1999) Constructed Wetlands and Mosquitoes: Health Hazards and Management Options—An Australian Perspective *Ecological Engineering* Vol 12, Issues 1-2, pp 107-124

Constructed wetlands designed to reduce contaminants before disposal into river systems provide habitat for mosquitoes that transmit pathogens such as malaria and arboviruses (e.g. Ross River virus in Australia). Disease transmission depends on mosquito species and abundance and extent of contact with humans; characteristics and siting of wetlands determine hazards and disease risk (e.g. shallow water and dense vegetation promote mosquito production whereas

deeper habitats with cleaner steeper margins, and more open water, produce fewer mosquitoes).

c) Marine areas

Byrnes JE, Reynolds PL, Stachowicz JJ (2007) Invasions and Extinctions Reshape Coastal Marine Food Webs *PloS ONE* 2(3):e295

The authors reveal how the combined effect of loss due to human-caused extinctions and species gain through intentional and accidental introductions is altering the trophic structure of food webs in coastal marine systems. Most extinctions occur at high trophic levels (top predators and other carnivores), while most invasions are by species from lower trophic levels. The consequences of this simultaneous loss are largely unknown.

Gjertsen H (2005) Can Habitat Protection Lead to Improvements in Human Well-being? Evidence from Marine Protected Areas in the Philippines *World Development* Vol 33 (2)

This paper reviews a study of community-based marine protected areas in the Philippines to determine tradeoff outcomes measured in terms of children's health and coral reef health. Disentangling the various factors that contribute to effective conservation and improved human welfare is difficult but necessary for understanding when these win-win scenarios are likely to emerge.

V. How can the economic value of health as an ecosystem service be quantified? What is the potential for market value?

Few publications exist relating health costs to environmental causes. Select documents from the environmental economic and valuation literature are provided as background references.

1) Valuation methods in environmental economics

Considerable literature and examples exist on alternative ways to value the environment in monetary/economic terms. Health examples appear in the context of water and agriculture or water and sanitation studies.

a) General references

World Health Organization/UN Environment Program (2008) Managing the Linkages for Sustainable Development: A Toolkit for Decision Makers (synthesis report) WHO/UNEP Health and Environment Linkages Initiative (HELI)
http://whqlibdoc.who.int/publications/2008/9789241563727_eng.pdf

Sponsored initially by the Government of Canada and supported by the US Environmental Protection Agency, HELI was designed to translate scientific knowledge on environmental threats to human health into policy action. In 2002, WHO and UNEP joined forces and HELI is now a global UN effort. It supports valuation of ecosystem 'services' to human health and well-being – services ranging from climate regulation to provision/replenishment of air, water, and food and energy sources. It builds upon UNEP and WHO's ongoing work with methods for quantifying the environmental impacts of policies and population health impacts (burden of disease). This report summarizes scientific knowledge on the linkages and Chapter IV highlights the importance of measuring impacts of the environment on health in economic terms. It describes how burden of disease and economic assessment have been used in real life settings to support sustainable policies.

TEEB (2008) The Economics of Ecosystems and Biodiversity: Interim Report http://www.teebweb.org/InformationMaterial/TEEBReports/tabid/1278/language/en-US/Default.aspx

Arising out of discussions among environment ministers at a G8+5 meeting in May 2007, a joint initiative was launched to draw attention to the global economic benefits of biodiversity and the costs of biodiversity loss and ecosystem degradation. Taking inspiration from ideas developed in the Millennium Ecosystem Assessment, the Economics of Ecosystems and Biodiversity (TEEB) project was developed to promote a better understanding of the true economic value of ecosystem services and to offer economic tools that take proper account of this value. The project recognizes that society is still learning the "nature of value" as we broaden our concept of "capital" to encompass human capital, social capital and natural capital. By recognizing and by seeking to grow or conserve these other "capitals", we are working our way towards sustainability. We are still struggling however to find the "value of nature". Nature's value mostly bypasses markets, escapes pricing and defies valuation - underlying causes for the observed degradation of ecosystems and the loss of biodiversity. Human, in turn, are suffering the consequences. The TEEB project is being conducted in two phases and this interim report summarizes the results of Phase I. It demonstrates the huge significance of ecosystems and biodiversity and the threats to human welfare if no action is taken to reverse current damage and losses. Phase II will expand on this and show how to use this knowledge to design the right tools and policies.

Pergams ORW, Zaradic PA (2006) Is Love of Nature in the US becoming Love of Electronic Media? 16-year Downtrend in National Park Visits explained by Watching Movies, Playing Video Games, Internet Use, and Oil Prices *Journal of Environmental Management* 80: 387–393 doi:10.1016/j.jenvman.2006.02.001

Per capita visits to US national parks have declined since 1988, coincident with the rise in electronic entertainment media. This may represent a shift in

recreation choices with broader implications for the value placed on biodiversity conservation and environmentally-responsible behavior. The authors compared the decline in per capita visits with a set of indicators representing alternate recreation choices and constraints. Multiple linear regression analyses of four entertainment media variables and oil prices explain most of the recent decline. The authors conclude that this may be evidence of a fundamental shift away from people's appreciation of nature towards a new tendency to focus on sedentary activities involving electronic media.

United States Agency for International Development (2004) Environmental Valuation for Watersheds and Water Resources. A Guide for USAID Missions, USAID Latin America and Caribbean Bureau and EGAT/Water Team

This document provides a succinct overview of valuation methods and issues related to water resources. It includes a table on selection criteria for choosing a valuation method and a brief review of case studies from the Caribbean.

Pergams ORW, et al. (2004) Linkage of Conservation Activity to Trends in the US Economy *Conservation Biology* Vol 18, No 6, pp 1617-1623

As an economy grows, natural capital such as timber, soil and water is reallocated to the human economy. The conflict between economic growth and biodiversity conservation creates a challenge as traditional forms of conservation action require funding. The authors reveal that conservation spending in the US was highly correlated with income and wealth and economic indicators (e.g., stock market indices) predicted conservation activity over time. However, GDP and personal income explained more variation in conservation activity that did stock-market wealth variables.

Environmental Protection Agency (2000) Guidelines for Preparing Economic Analyses EPA 240-R-00-003 http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/Guidelines.pdf

This report discusses cost benefit analysis, economic impact analysis, and equity assessments as part of EPA's continuing effort to improve guidance on the use of sound science to support decision-making.

Barbier EB, Acreman M, Knowler D (1997) Economic Valuation of Wetlands: A Guide for Policymakers and Planners Ramsar Convention Bureau, IUCN, 127 pp.

This book provides details of techniques and examples of wetland valuation studies to help policy makers and planners understand the potential for economic valuation of wetlands and how such studies should be conducted.

Pearce D, Moran D (1994) Methodologies for Economic Valuation Chapter 5 in the Economic Value of Biodiversity, Earthscan http://www.esm.ucsb.edu/academics/courses/245/Presentations/11_13_08_Valuation_Methods_in_Environmental_Economics.pdf

The authors review direct approaches (i.e., direct observation of people's behavior in a market situation – what they pay - or direct questioning) and indirect ones (valuations estimated by inference from behavior not directly related to the specifics of the environment assets of interest). Examples of indirect approaches include: i) hedonic valuing (to identify implicit differences in valuation between situations with an attribute and others without it), ii) avertive behavior (valuation of a change as costs incurred to avoid the change), iii) conventional market approach (market values where prices exist) iv) dose response (observing or introducing a change and measuring the cost/benefit of attributable consequences) and v) replacement cost (valuation on the basis of costs incurred to replace or restore the lost asset).

Winpenny JT (1991) Values for the Environment: A Guide to Economic Appraisal, Overseas Development Institute

The author describes various valuation methods: i) effect on production approach (to determine and evaluate physical effects), ii) preventive expenditure (what people will pay to prevent something happening), iii) replacement cost (payment made to restore something to original state or something equivalent); iv) human capital (effect of environmental changes on the value of humans as productive assets); and v) contingent valuation (e.g. willingness to pay and willingness to accept).

Dixon JA, Sherman PB (1990) Valuing the Benefits Chapter 2 in Economics of Protected Areas- A New Look at Benefits and Costs, Earthscan

The authors describe valuing techniques including those based on market prices in which effects are measured in terms of outputs/costs of items having a market, e.g. change in productivity where the value of net benefits is compared with and without change, and loss of earnings in which valuation is measured as change in earnings arising from change. Techniques based on surrogate market prices determine the value from a price paid for a closely associated good (or service) that has a market., e.g. "hedonic" pricing (property value or wage differential) and travel costing. Survey-based approaches for nonmarket situations involve asking people about their value reactions to specific situations, e.g. contingent valuation (people give their reaction to possible changes in a factor) and compensating variation ("ex-ante" determining the value of compensation needed/payment offered to accept a proposed change). Equivalent variation "ex-post" values the compensation needed/payment offered to avoid return to the initial state.

Cost-based approaches include, i) opportunity cost of lost benefits (valuing the net benefits forgone from not doing something, e.g., alternative use for agriculture), ii) alternative cost (valuing alternative means of supplying net benefits lost or the cost of generating them in a way other than the one in view) and iii) cost effectiveness to find the least-costly means of achieving a specific objective. Expenditure-based approaches include: i) costs of creating benefits/reducing losses in another place/way, ii) preventive expenditure approach or costs incurred to alleviate a problem, iii) mitigation cost approach (cost of mitigating or reversing a loss), iv) replacement cost approach (cost of replacing assets in another place), and v) shadow project (supplementary project to replace losses with equivalent assets).

b) Cost-effectiveness analysis

Hutton G (2000) Considerations in Evaluating the Cost Effectiveness of Environmental Health Interventions, World Health Organization WHO/SDE/WSH/00.10

The aim of health economic studies is to make optimal use of resources expended in the health sector. 'Optimal' refers to efficiency (maximum health gains) and equity (appropriate distribution of health gains). Environmental health interventions differ from core health services as they are almost exclusively preventive and their benefits may not be realized until the distant future. They potentially convey considerable non-health benefits e.g., saving time ,which should be included when analyzing from a societal perspective. Importantly, environmental health interventions may hold gains already achieved, preventing 'back-sliding'. The effectiveness of such interventions is difficult to evaluate as they are less amenable to controlled experiments (with the long time periods involved) and their impact on potentially large population may be small. Thus environmental health interventions are often considered much less cost-effective than many curative measures.

c) Cost-benefit analysis

International Institute for Environment and Development (2003) Valuing Forests: A Review of Methods and Applications in Developing Countries Environmental Economics Programme, IIED pp.159

Forest economic benefits can be grouped into direct and indirect uses, option and non-use values. Most studies of forest land use options in developing countries concentrate on direct use values. Methods involve market prices but data on quantities and inputs are often difficult to obtain. Methods to estimate their total economic value include marketed and non-marketed benefits e.g. valuation using market prices, surrogate market approaches, production function method, stated preference and cost-based techniques. Each has its strengths and weaknesses and certain ones are better suited to particular forest goods and services. Valuation

methods are particularly useful for extending the reach of cost-benefit analysis (CBA) to include non-market environmental impacts in assessing alternative forest land uses. CBA is particularly useful for illuminating tradeoffs.

Hanley N (1992) Are there Environmental Limits to Cost Benefit Analysis? *Environmental and Resource Economics* Vol 2, No 1

This paper considers problems applying cost-benefit analysis (CBA) to projects involving environmental costs or benefits. It argues that a major problem lies in placing monetary values on non-market goods. It also addresses the problems of (i) differences between citizen and consumer values; (ii) complexity of ecosystems; (iii) irreversibility and uniqueness; and (iv) inter-generational equity and discounting.

d) Contingent valuation

Hanley N, Ryan M, Wright R (2003) Estimating the Monetary Value of Health Care: Lessons from Environmental Economics *Health Economics* Vol 12, Issue 1, pp 3-16

The application of contingent valuation (CV) in environmental economics has a long history and is widely accepted. There is skepticism concerning the value of stated preference methods such as CV for health economics. This paper identifies some of the key issues and debates that have taken place in the environmental economics literature and how health economists have addressed these issues.

e) Willingness to pay

Zhongmin X, et al. (2003) Applying Contingent Valuation in China to Measure the Total Economic Value of Restoring Ecosystem Services in Ejina Region *Ecological Economics* 44: 345-358.

CV was used to obtain estimates of willingness to pay (WTP) for restoring ecosystem services in rural China using a parametric model. Interviews revealed that households were willing to pay but the amount per household was higher for the main river area versus households in the rest of the basin. Additionally, while the surrounding general public was willing to pay to restore the ecosystem, the amount was substantially less than the estimated restoration costs.

Dixon, J (1998) Economic Valuation of Health Impacts, The World Bank

Valuing health impacts of the environment has been limited as it was considered i) too difficult to establish direct cause-effect relationships or ii) not feasible to place monetary values on the effects (health or productivity). Ideally, such valuation should include both out-of-pocket costs of illness (e.g. medical costs, lost income and averting expenditures) as well as less tangible effects of illness on well-being (e.g. pain, discomfort and restriction in non-work activities). Health

impacts valued by WTP incorporate all of these impacts, whereas a cost of illness (COI) approach only includes out-of-pocket expenses.

Choe K, Whittington D, Lauria DT (1996) Economic Benefits of Surface Water Quality Improvements in Developing Countries: A Case Study of Davao, Philippines *Land Economics*, Vol 72, No 4, pp 519-537 http://www.jstor.org/stable/3146913

Two nonmarket valuation techniques- CV and the travel cost model-are used to estimate the economic value that people in the Philippines place on improving the water quality of rivers and the sea near their community. Both estimates approximate each other and are low in both absolute terms and as a percentage of household income. This suggests that water pollution control is not a high priority for local residents and support the argument that households' willingness to pay for environmental amenities such as improved water quality is low.

Echeverria J, Hanrahan M, Solorzano R (1995) Valuation of Non-priced Amenities provided by the Biological Resources within the Monteverde Cloud Forest Preserve, Costa Rica *Ecological Economics* 13: 43-52

The study uses CV to show that Costa Ricans are willing to pay more than non-Costa Ricans despite having a lower income, possibly explained by greater concern for their own well being.

f) Benefits transfer

Smith VK, Pattanayak SK, Van Houtven GL(2006) Structural Benefit Transfer: An Example using VSL Estimates *Ecological Economics* Vol 60, Issue 2, pp 361-371 doi:10.1016/j.ecolecon.2006.04.002

This paper describes and illustrates preference calibration or structural benefits transfer as a benefits transfer method. A preference model is selected, capable of describing individual choices over a set of market and associated non-market goods to maximize utility when facing budget constraints. Next analytical expressions are determined for the tradeoffs represented by available benefit measures. The algebraic relationships are combined with benefit estimates from the literature to calibrate model parameters. The model provides a basis for defining "new" tradeoffs required for 'transferring benefits'.

A different application illustrates the structural benefits transfer logic involving the benefits of mortality risk reduction, measured by the labor market compensation a worker would accept to work with added risk [labeled the value of a statistical life (VSL)]. Findings show no difference in these measures for the economic value of risk reductions with age. This suggests simple adjustments relying on value per discounted life year remaining are questionable.

Knowler DJ (2004) The Economics of Soil Productivity: Local, National and Global Perspectives *Land Degradation & Development* Vol 15, Issue 6, pp 543-561

Soil degradation is a mounting problem on many smallholder lands in developing countries. Economic analysis helps address the problem beginning with assessments of the financial attractiveness of investing in soil conservation works. Devising effective incentives at the farm or community (collective action) level should be a priority. As soil degradation is a problem with global ramifications, intervention at the international level via mechanisms such as international transfers is warranted.

Barton DN, Mourato S (2003) Transferring the Benefits of Avoided Health Effects from Water Pollution Between Portugal and Costa Rica *Environment and Development Economics* 8: 351-371

Two CV surveys elicited information on willingness-to-pay (upper and lower bounds) to avoid eye irritation, gastroenteritis, and coughing episodes due to seawater pollution among beach visitors in two countries. Health benefit transfer from one to the other lead to very high errors illustrating the challenge of applying this approach across different countries - and how doing so could be inappropriate (and potentially harmful) for informing policy.

g) Production function

Tallis H, Polasky S (2009) Mapping and Valuing Ecosystem Services as an Approach for Conservation and Natural-Resource Management *Annals of the New York Academy of Sciences* Vol 1162, pp 265-283

The authors describe a set of computer-based models, the "Integrated Valuation of Ecosystem Services and Tradeoffs" tool (InVEST) that apply a production function-based approach to natural-resource decision making. The tool allows the user to visualize relationships among multiple ecosystem services and biodiversity, focusing on ecosystem services rather than biophysical processes.

Nelson E, et al. (2009) Modeling Multiple Ecosystem Services, Biodiversity Conservation, Commodity Production and Tradeoffs at Landscape Scales *Front Ecol Environ*; 7(1): 4–11

The authors use InVEST, a spatially-explicit modeling tool, to predict changes in ecosystem services, biodiversity conservation, and commodity production levels. In an analysis of stakeholder-defined scenarios of land-use/land-cover change in the US, high scoring scenarios for a variety of ecosystem services had high scores for biodiversity. This suggests there was little tradeoff between biodiversity conservation and ecosystem services. Development scenarios had higher commodity production values but lower levels of biodiversity conservation and ecosystem services.

Naidoo R, Malcol T, Tomasek A (2008) Economic Benefits of Standing Forests in Highland Areas of Borneo: Quantification and Policy Impacts *Conservation Letters* Vol 2 Issue 1, pp 36 - 45

The authors demonstrate that a rapid assessment of the benefits of standing forests in the highlands of Borneo was feasible and provided useful and timely information for conservation policy decisions. They used existing biophysical and economic information to characterize values associated with forests in areas proposed for oil palm plantation development focusing on three classes of benefits: avoided damages associated with increased greenhouse gas emissions (carbon storage), avoided damages associated with increased fires, and the economic benefits of forest–agriculture mosaics. Carbon storage values dominated the overall value of standing forests and were of similar magnitude to benefits from oil palm plantations. Other values were smaller but important to different stakeholder groups.

Barbier EB (2007) Valuing Ecosystem Services as Productive Inputs *Economic Policy* Vol 22, Issue 49, pp 177-229

Two methods for valuing ecosystems (production function and expected damage) were applied to mangrove ecosystems in Thailand. The former reflects how ecosystem services not directly valued in the market may be inputs into the production of other goods or services that are marketed, such as fisheries. The latter approach is used to value the reduction in expected future storm damage that the ecosystem can provide. The shadow value of the ecosystem consists in its contribution to fish stock maintenance as well as to current output. These two methods yield very different valuations from those derived by methods typically used in cost-benefit analyses.

h) Cost of avertive behavior

Sarraf M, Larsen B, Owaygen M (2004) Cost of Environmental Degradation - The Case of Lebanon and Tunisia Environmental Economic Series, Paper No. 97, The World Bank

This report represents an attempt to quantify and monetize the cost of degradation across a wide range of environmental issues in the region. Methodological harmonization was used to estimate and value health effects of urban air pollution, indoor air pollution, and inadequate water, sanitation and hygiene. Cost of avertive behavior was used for drinking water quality issues. The productivity method was applied to agricultural land degradation. A combination of methodologies was used including CV and hedonic property pricing to assess costs associated with coastal degradation, inadequate waste management, and natural resource degradation other than agricultural land.

i) Marginal value of undisturbed land

Balmford A, et al. (2002) Economic Reasons for Conserving Wild Nature *Science* 297: 950-953

The authors selected a few case studies as baseline measures of total economic value (TEV) for four biomes: tropical forests, mangroves, freshwater marshes and reefs. With the baseline they estimated the loss of economic value due to conversion of those biomes. The difference was then considered as the marginal value of one hectare of undisturbed ecosystems.

2) Lessons learned from ecosystem service valuation studies

a) Value multiple benefits from the same area

Pattanayak SK, Wendland KJ (2007) Nature's Care: Diarrhea, Watershed Protection and Biodiversity Conservation in Flores, Indonesia *Biodiversity and Conservation* Vol 16, No 10 doi: 10.1007/s10531-007-9215-1

This paper looks at links between biodiversity conservation and the livelihoods of rural people living on the fringes of Ruteng Park, Flores Island, Indonesia as an empirical example of ecosystem valuation. Spatially patchy watershed protection allowed for impacts of watershed services on human health (diarrhea prevalence) in the park's buffer zone to be estimated. In this case study reported diarrhea reduction benefits were not likely high enough on their own to justify the costs of the protected area. But when combined with previous analyses from Ruteng Park on ecosystem services, the investigators found that the park provides an entire suite of economically valuable services. Recommendations included: scaling up valuation efforts of underappreciated services such as health; and shifting focus from valuing services individually to valuing multiple benefits from the same area.

b) Incorporate natural variability

Koch EW, et al. (2009) Non-linearity in Ecosystem Services: Temporal and Spatial Variability in Coastal Protection *Front Ecol Environ* 7(1): 29–37

It is often assumed that ecosystem services are provided linearly (unvaryingly, at a steady rate), but natural processes are characterized by thresholds and limiting functions. The authors describe the variability observed in wave attenuation provided by marshes, mangroves, seagrasses, and coral reefs and therefore in coastal protection. They calculate the economic consequences of assuming coastal protection to be linear, suggesting that natural variability and cumulative effects must be considered in the valuation of ecosystem services**.**

c) Include beneficiaries

Brauman KA, et al. (**2007)** The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services *Annual Review of Environment and Resources* Vol 32: 67-98

The explicit inclusion of beneficiaries makes values intrinsic to ecosystem services whether or not those values are monetized. The authors provide an overview of ecosystem functions responsible for producing terrestrial hydrologic services, review valuation tools useful for ecosystem service protection and provide examples of land management using these tools.

d) Focus on critical natural capital

Farley J (2008) The Role of Prices in Conserving Critical Natural Capital *Conservation Biology* Vol 22, Issue 6**,** pp 1399 - 1408

One of today's economic challenges is to decide how much ecosystem structure can be converted to economic production and how much must be conserved to provide essential ecosystem services. The author estimates the marginal value of environmental benefits by examining the role and effectiveness of the price mechanism in a well-functioning market economy. Issues preventing markets from pricing ecological benefits are considered including problems inherent to valuing services generated by complex and poorly understood ecosystems subject to irreversible change. The author focuses on critical natural capital (CNC), i.e. capital that generates benefits essential to human welfare that have few if any substitutes. When ecological thresholds threaten CNC, the author argues conservation is essential and marginal valuation becomes inappropriate. Only when conservation needs have been met should remaining ecosystem structure be potentially available for economic production. Demand for this available supply will determine prices. That is, conservation needs should be price determining, not price determined.

e) Pricing versus valuation

Turner K, et al. (2004) Economic Valuation of Water Resources in Agriculture from the Sectoral to a Functional Perspective of Natural Resource Management, Food and Agriculture Organization http://www.fao.org/docrep/007/y5582e/y5582e00.HTM

Pressures on agriculture to reduce its 'successful' capture of raw water will require transparent methods of negotiation. The authors purport there is confusion between the basic economics of natural resource allocation and the implications of water valuation and its relationship to water 'pricing'. This publication focuses on agricultural use of water as it will continue to dominate global water withdrawals.

f) Lack of market prices

TEEB (2009) The Economics of Ecosystems and Biodiversity for National and International Policy Makers: Summary - Responding to the Value of Nature http://www.teebweb.org/InformationMaterial/TEEBReports/tabid/1278/language/en-US/Default.aspx

This report reveals how the failure of markets to adequately consider the value of ecosystem services is of concern not only to environment, development and climate change ministries but also to finance, economics and business ministries. The lack of market prices for ecosystem services and biodiversity means that the benefits humans derive from these goods (often public in nature) are usually neglected or undervalued in decision-making. This in turn leads to actions that not only result in biodiversity loss, but also impact on human well-being. The report demonstrates that understanding and capturing the value of ecosystems can lead to better informed and possibly different decisions; accounting for such value can result in better management; investing in natural capital can yield high returns; and sharing the benefits of these actions can deliver real benefits to those worst off in society. The report further shows how appreciating the value of biodiversity has led to policy changes, how investment in natural capital can be more cost-effective than man-made solutions and how conservation can deliver a range of economic advantages.

g) Correspondence

Plummer ML (2009) Assessing Benefit Transfer for the Valuation of Ecosystem Services *Front Ecol Environ*; 7(1): 38–45 doi:10.1890/080091

Gathering primary, site-specific data to value ecosystem services is costly; a popular alternative is a "benefit transfer" e.g. applying an estimate of value per hectare to all areas having the same land-cover or habitat type. This approach is particularly susceptible however to errors from lack of correspondence between locations.

h) Improve restoration success

Palmer MA, Filoso S (2009) Restoration of Ecosystem Services for Environmental Markets *Science* 31 Vol 325. No 5940, pp 575 - 576 doi: 10.1126/science.1172976

Ecological restoration ideally results in the return of an ecosystem to an undisturbed state. Ecosystem services are the benefits humans derive from ecosystems. The two have been joined to support growing environmental markets with the goal of creating restoration-based credits that can be bought and sold. However, the allure of these markets may be overshadowing shortcomings in the science and practice of ecological restoration. Before making risky investments, the authors argue we must understand why and when restoration efforts fall short of recovering the full suite of ecosystem services, what can be done to improve restoration success, and why direct measurement of the biophysical processes

that support ecosystem services is the only way to guarantee the future success of these markets. Without new science and an oversight framework to protect the ecosystem service assets upon which people depend, markets could actually accelerate environmental degradation.

i) Risks associated with the ecosystem services approach

Redford KH, Adams WM (2009) Payment for Ecosystem Services and the Challenge of Saving Nature *Conservation Biology*, Vol 23, No 4, pp 785-787

The strategic importance of ecosystem services as a tool for conservation is obvious. The strategy of payment for ecosystem services has enormous potential to help in heretofore largely unsuccessful efforts to sway humanity's view on the value of nature. There are risks, however, in the speed and uncritical enthusiasm with which the strategy is being applied. Skepticism about this enthusiasm for payment for ecosystem services is, in our experience, often met with sharp rebuke, frequently correct in the technical details, but ducking wider strategic issues. Yet some skepticism is warranted. There are risks as well as benefits in the ecosystem services approach, and it is important that these be considered and addressed. If conservation places too much emphasis on payment for ecosystem services in its strategies, we may stop thinking hard about the wider consequences. This would be a disaster. Ecosystem services are extremely important but need to be drawn into conservation strategies with great care.

3) Market mechanisms to generate funds to conserve ecosystem health function

Grigg A, et al. (2009) The Ecosystem Services Benchmark. A Guidance Document Fauna & Flora International, United Nations Environment Programme Finance Initiative and Fundação Getulio Vargas

Despite emerging risks and opportunities, there are few tools available to enable investors to understand the extent to which companies are dependent or impact on biodiversity and ecosystem services. As a result, company exposure to these risks is unclear. Investors can potentially gain competitive advantage by identifying companies that are managing their risks and capturing opportunities, flagging them as stronger performers within their portfolio. The Natural Value Initiative, an initiative led by Fauna & Flora International in collaboration with the United Nations Environment Programme Finance Initiative and Brazilian business school Fundação Getulio Vargas, aims to address this gap by creating a toolkit to enable institutional investors to better understand the impacts and dependency of their investments on biodiversity and ecosystem services.

Zaradic PA, Pergams ORW, Kareiva P (2009) The Impact of Nature Experience on Willingness to Support Conservation *PLoS ONE* 4(10): e7367. doi:10.1371/journal.pone.0007367

The authors tested the hypothesis that willingness to financially support conservation depends on one's experience with nature using a novel time-lagged correlation analysis. Specifically, they evaluated the relationship of times series data concerning nature participation with future conservation support (measured as contributions to conservation NGOs 11-12 years later). Their results revealed differences in future conservation investment according to the type and timing of nature experience (e.g. hiking versus fishing) suggesting that current declines in the former will negatively impact future contributions to conservation NGOs.

Riggsbee A, Doyle MW (2009) Environmental Markets: The Power of Regulation *Science* 326(5956): 1061

In this *Science* letter regarding Palmer and Filoso's previous article "Restoration of Ecosystem Services for Environmental Markets", the authors agree that direct measurement of ecosystem processes and third-party verification are critical steps. They also agree that more stringent criteria must be established for restoration as part of ecosystem markets. These authors argue that making restoration success criteria more rigorous will increase costs and verification of project success will add yet an additional expense. Financial risks will increase with greater uncertainty causing investors to increase required rates of return. The net result will be an increase in mitigation costs which will need to be recouped by charging more for mitigation credits. This will, in turn, drive up the costs of affecting ecosystems, serving as a deterrent to damaging them. They present the case that increased restoration quality requirements could reduce the demand for compensatory mitigation by providing incentives for avoidance. This they feel is likely the most substantial benefit of more expensive restoration.

Heal G (**2000)** Nature and the Marketplace: Capturing the Value of Ecosystem Services, Island Press

This book evaluates real prospects for nature's marketable services to "turn profits" at levels exceeding profits expected from alternative, ecologically destructive, activities. It offers an assessment of how market approaches can be used to protect the environment, illustrating cases in which the value of ecosystems has actually been captured by markets. It considers economic activities such as ecotourism, bio-prospecting and carbon sequestration where market forces can provide incentives for conservation. It also examines policy options other than the market such as pollution credits and mitigation banking.

a) Payment for ecosystem services

Arriagada RA, et al. (2009) Combining Qualitative and Quantitative Methods to Evaluate Participation in Costa Rica's Program of Payments for Environmental Services *Journal of Sustainable Forestry*, 28:343–367
doi: 10.1080/10549810802701192

The Costa Rican Program of Payments for Environmental Services provides financial compensation to forest owners for the environmental services generated

by their forests, offering an opportunity to evaluate the causal effect of direct incentive payments on conservation. Economic theory suggests that opportunity costs are critical but many factors determine and mediate the influence of these costs. The study found that program participation depended on socioeconomics. People leaving their forests unmanaged participated (none however depended on their farms to survive) as did farms without good alternative land uses. Legal issues, property protection and opportunity costs also influenced participation.

McNeely JA (2007) A Zoological Perspective on Payments for Ecosystem Services *Integrative Zoology* Vol 2, Issue 2, pp 68-78

Payments for ecosystem services provide a more diverse flow of benefits to people living in and around habitats valuable for conservation e.g. payment for carbon sequestration. Another is compensating upstream landowners for managing their land in ways that maintain downstream water quality. Biodiversity itself is difficult to value but it can be linked to other markets such as certification in the case of sustainably-produced forest products. This paper explores potential markets that also benefit wildlife.

Pattanayak SK (2004) Valuing Watershed Services: Concepts and Empirics from Southeast Asia *Agriculture, Ecosystems & Environment* Vol 104, Issue 1, pp 171-184 doi:10.1016/j.agee.2004.01.016

Few empirical studies have analyzed downstream economic benefits of watershed protection to generate economic values of watershed services. Using household level economic and environmental data, this paper addresses the importance of watershed services to farming communities in SE Asia (Flores, Indonesia). It provides evidence of a substantive, quantified economic benefit of watershed service based on a fixed-effects regression model of water collection costs.

b) Payment for restoration

Holl KD, Howarth RB (2000) Paying for Restoration *Restoration Ecology* Vol 8, Issue 3, pp 260-267

The authors explore how ecological and economic considerations should be balanced in determining expenditures on restoration projects and how society is going to pay for the substantial costs involved. Techniques reviewed for determining the amount of money to allocate to restoration include i) ecosystem replacement costs, ii) quantifying ecosystem services, iii) contingent valuation, and iv) surrogate market price techniques. They review different strategies for paying for restoration including private funding by the party responsible for the damage, public funding through taxes, voluntary contributions, and various public/private partnerships.

c) Insurance value of biodiversity

Baumgärtner S (2007) The Insurance Value of Biodiversity in the Provision of Ecosystem Services *Natural Resource Modeling* Vol 20, Issue 1, pp 87-127

The author presents a conceptual ecological-economic model and determines the insurance value of biodiversity considering the optimal allocation of funds in trade-offs between investing into biodiversity protection and the purchase of financial insurance. He concludes that biodiversity acts as a form of natural insurance for risk-averse ecosystem managers against the over- or under-provision with ecosystem services. Therefore, biodiversity has an insurance value additive to the usual value arguments (e.g. direct or indirect use or non-use values) and thus biodiversity and financial insurance are substitutes.

Pattanayak SK, Sills EO (2001) Do Tropical Forests Provide Natural Insurance? The Microeconomics of Non-Timber Forest Product Collection in the Brazilian Amazon *Land Economics* 77(4):595-612

Tropical forests may contribute to the well-being of local people by providing a form of "natural insurance." The authors conceptualize a model relating agricultural risks to collection of non-timber forest products. Forest collection trips are positively correlated with agricultural shocks and expected agricultural risks in an event-count model using survey data from the Brazilian Amazon. Results suggest that households rely on forests to mitigate agricultural risk. Forest product collection may be less important to households with other consumption-smoothing options but its importance is not restricted to the poorest households.

d) Debt-based investment

Mandel JT, et al. (2009) Debt Investment as a Tool for Value Transfer in Biodiversity Conservation *Conservation Letters* Vol 2, Issue 5**,** pp 233 - 239

Direct valuation approaches such as land purchases and cash payments through conservation incentive agreements and regular payments for ecosystem preservation are being trialed in low-income nations. Challenges include the lack of enforceable property rights and contractual laws. The authors suggest debt-based investment as an alternative that capitalizes environmental assets locally and makes that capital available to local communities through collateralized lending, microfinance approaches, and access to affordable financial services. Tying the value of capital in a conservation lending trust to the overall value for intact environmental resources creates incentives for local environmental stewardship while providing economic access to what is often a poor community's most valuable asset—intact natural resources.

e) Resource culturing

Adey WH (2001) Coral Reef Ecosystems and Human Health: Biodiversity Counts! *Ecosystem Health* Vol 6, Issue 4, pp 227 - 236

This article focuses on the pharmacological value of ecosystem biodiversity and how natural product chemistries are an extremely important resource for human health. High diversity density gives rise to intense species competition and subsequent organism capability to construct exotic defensive and offensive chemicals, many with pharmacological value. Coral reefs have the highest density of biodiversity globally and are being rapidly degraded. Sophisticated coral reef and reef organism culturing capability is available that would allow for prospecting of reefs, efficient analysis of organisms and eventually mass culturing of organisms for their secondary compounds without ecosystem damage. The economic value of this pharmaceutical potential needs to be considered as a means of conserving coral reefs and their biodiversity.

f) Producer surplus approach

Pattanayak SK, Kramer R (2001) Worth of Watersheds: A Producer Surplus Approach for Valuing Drought Control in Eastern Indonesia *Environment and Development Economics* 6(1):123-45.

This study combines hydrological modeling with applied micro-econometric techniques to value a complex ecosystem service: drought mitigation provided by tropical forested watersheds to agrarian communities. Spatial variation in current base flow allows estimation of drought mitigation values as the marginal profit accruing to agricultural households. The paper shows that focusing on producer (not consumer) surplus measures is appropriate for valuation as long as markets for commodities related to the environmental services are complete. For the typical household, the estimated marginal profit is positive -validating the central hypothesis that base flow makes positive contributions to agricultural profits. The paper provides support for the hypothesis that protected watersheds can supply latent and unrecognized ecosystem services to local people.

g) Create enterprise option value

Figge F (2005) Value-based Environmental Management. From Environmental Shareholder Value to Environmental Option Value *Corporate Social Responsibility and Environmental Management* Vol 12, Issue 1, pp 19-30

Concepts linking environmental management and enterprise value are usually based on net present value approaches. This approach risks making companies (eco) efficient but vulnerable to environmental and social shocks. This article discusses environmental option value as a compliment to concepts such as environmental shareholder value. It creates flexibility allowing investors to be shielded from detrimental effects of possible future environmental and social shocks. In combination the two approaches can help environmental management to contribute to creating long-term enterprise value.

h) Concentrate on criteria

Wu T, Kim Y-S (2009) Environmental Markets: Concentrate on Criteria *Science* 326(5956): 1060

In this *Science* commentary regarding Palmer and Filoso's article "Restoration of Ecosystem Services for Environmental Markets", the authors note that well-defined markets delineate which services are relevant and the biophysical processes that underlie them. They argue that environmental markets are indispensable compasses for restoration initiatives and that focus should be on developing and improving valuation criteria, not on adding costly mechanisms that might discourage development. They believe that it is often better to have imperfectly functioning environmental markets, in which nature has some economic value, than to have no environmental markets, where nature possesses zero value. This fits into the broader notion of ecosystems as assets from which society derives vital services. Ecological restoration, then, is not merely a rehabilitation of biophysical processes but an investment in natural capital.

4) Methods for measuring relevant human health impacts

a) DALYs and Burden of disease

Rehfuess EA, Bruce N, Bartram JK (2009) More Health for your Buck: Health Sector Functions to Secure Environmental Health *Bulletin of the World Health Organization* 87: 880-882 doi: 10.2471/BLT.08.059865

Modifiable environmental risk factors are responsible for approximately one quarter of the global burden of disease (BOD). This BOD is very unequally distributed with 15 times more healthy life years lost per capita in developing versus developed countries. Diarrhoea and acute lower respiratory infections among children are the largest contributors and the two principal environmental risk complexes for these diseases – drinking water/ sanitation/hygiene and indoor air pollution from solid fuel use – cause more than 2 million deaths annually. Known effective solutions include: ensuring that households have access to and use safe drinking-water and improved sanitation facilities; encouraging household water treatment; promoting the use of cleaner-burning stoves and switching from traditional solid fuels to cleaner modern fuels. They are good value for money, yielding health-care savings, health-related productivity gains, time savings and environmental benefits that far exceed costs. Delivery of environmental health interventions, on the other hand, is rarely administered or controlled directly by the health sector and uncertainty about leadership and responsibility across the many public and private actors contributes to overall underperformance and inefficiency in this area.

World Health Organization (2008) The Global Burden of Disease: 2004 Update
http://www.who.int/healthinfo/global_burden_disease/2004_report_update/en/index.html

A consistent and comparative description of the burden of diseases and injuries, and risk factors that cause them, is an important input to health decision-making

and planning processes. Information available on mortality and health in populations in all regions of the world is fragmentary however and sometimes inconsistent. Thus, a framework for integrating, validating, analyzing and disseminating such information was needed to assess the comparative importance of diseases and injuries in different populations. The first Global Burden of Disease Study quantified the health effects of more than 100 diseases and injuries for eight regions of the world in 1990 and introduced DALY as a new metric. The DALY is based on years of life lost from premature death and years of life lived in less than full health. One DALY can be thought of as one lost year of "healthy" life and the burden of disease can be thought of as a measurement of the gap between current health status and an ideal situation - where everyone lives into old age, free of disease and disability. This document presents updated BOD assessments for the years 2000–2002 and a framework for cost-effectiveness and priority setting analyses carried out for the Disease Control Priorities Project (DCPP), a joint project of the World Bank, WHO and the National Institutes of Health, funded by the Bill & Melinda Gates Foundation.

King CH, Bertino AM (2008) Asymmetries of Poverty: Why Global Burden of Disease Valuations Underestimate the Burden of Neglected Tropical Diseases *PLoS Negl Trop Dis* 2(3): e209

It was originally thought that the DALY - a comprehensive health metric that encompasses premature mortality, morbidity, impairment, and disability - would be useful in policy settings as it reflects normative valuations as a standardized unit of ill health. However, its design and use in policy estimates have resulted in systematic undervaluation of the global importance of chronic diseases such as many of the neglected tropical diseases (NTDs). Specifically, the DALY focuses mostly on individual risk rather than disease ecology and thus fails to acknowledge the implications of context on the burden of disease for the poor. It does not consider the impact of poverty on disability which consequently significantly underestimates disability weights for chronic diseases including NTDs. Additionally, policy estimates involving DALYs do not account for the non-linear effects of poverty in cost-utility analyses of disease control which effectively discounts the utility of comprehensively treating NTDs. The authors conclude that the current DALY framework needs to be substantially revised if the global burden of disease is to become a valid and useful system for determining health priorities.

Airoldi M (2007) Gains in QALYs vs DALYs averted: the Troubling Implications of Using Residual Life Expectancy *LSE Health Working Paper* Number 8, London School of Economics and Political Science

This paper explores the difference between QALYs gained and DALYs averted in estimates of health benefits from interventions (where DALYs are estimated using local life expectancy tables). The author assumes that: disability weights in the DALYs framework correspond to quality adjustment weights in QALYs; there is no age weighting and both frameworks use the same discounting methodology. Analyses reveal that for the same intervention, health benefit measured as a

reduction in DALYs is always smaller than the same benefit measured as a gain in QALYs. The higher the age of deaths prevented by the intervention, and the lower the quality of life in the years of life gained, the bigger the difference between DALYs and QALYs. The difference is reduced when benefits are discounted. Differences can lead to a different ranking in cost-effectiveness league tables based on DALYs averted compared to gains in QALYs. The author concludes that the use of the DALY framework based on local life expectancy tables might be appropriate for estimating the total burden of disease, but leads to troubling results if used for cost-effectiveness analysis. Use of a fixed reference age would avoid those implications but might not be a reasonable assumption for estimating the total burden of disease.

Prüss-Üstün A, Corvalán C (2006) Preventing Disease through Healthy Environments: Towards an Estimate of The Environmental Burden of Disease, World Health Organization
http://www.who.int/quantifying_ehimpacts/publications/preventingdisease.pdf

This study examines how specific diseases and injuries are impacted by environmental risks, and regions and populations most vulnerable to environmentally-mediated diseases and injuries. Approximately one-quarter of the global disease burden and more than one-third of the burden among children is due to modifiable environmental factors. Diseases most impacted by the environment are diarrhoea, lower respiratory infections, various forms of unintentional injuries and malaria. This 'environmentally-mediated' disease burden is much higher in the developing world than in developed countries and children bear the highest death toll.

Corvalan C, Hales S, McMichael A (2005) Ecosystems and Human well-being: Health Synthesis, World Health Organization

This report synthesizes findings from the Millennium Ecosystem Assessment (MA) on ecosystem changes and human health and well-being. Burden-of-disease (BOD) evaluation is an appropriate tool for estimating and aggregating health impacts attributable to one particular or to a range of ecosystem mechanisms. The overall BOD caused by environment change can be measured in terms of disability-adjusted life years (DALYs) that allow health impacts - experienced as a result of multiple causes or through multiple causal pathways - to be summed together. Potentially this allows direct comparisons of the effects of different ecological changes on population health.

Hughes G, Lvovsky K, Dunleavy M (2001) Environmental Health in India: Priorities in Andhra Pradesh, The World Bank

This report examines linkages between health, particularly child survival, in India and the quality of the household environment, addressing both indoor air quality related to cooking fuel use and access to water and sanitation. It estimates the contribution of environmental factors to the BOD in Andhra Pradesh.

Murray CJL, Lopez AD (1996) (eds) Global Burden of Disease A Comprehensive Assessment of Mortality and Disability from Diseases, Injuries, and Risk Factors in 1990 and Projected to 2020, Harvard University Press

The Global Burden of Disease and Injury Series analyses global patterns of death and disability and provides estimates for 150 major health conditions. It is unique in its inclusion of disability and the authors explain the indicator developed: the DALY. Among the results listed, by 2020 pneumonia and diarrhea, both primarily diseases of childhood, will continue to inflict the greatest health burden of all.

Murray CJ (1994) Quantifying the Burden of Disease: the Technical Basis for Disability-adjusted Life Years *Bull World Health Organ* 72(3):429-45

Detailed assumptions used in constructing the DALY, a burden of disease indicator, are presented. DALYs use a standard expected-life lost, life table approach. The value of time lived at different ages is captured through an exponential function reflecting the dependence of young and the elderly on adults. Time lived with a disability is compared with the time lost due to premature mortality by defining six classes of disability severity (weighted between 0 and 1).

b) Cost effectiveness

Tediosi F, et al. (2006) Predicting the Cost-effectiveness of Introducing a Pre-erythrocytic Malaria Vaccine into the Expanded Program on Immunization in Tanzania *Am J Trop Med Hyg* 75(2 suppl):131-43

The authors model the cost-effectiveness of introducing a malaria vaccine into the Expanded Program on Immunization using a dynamic stochastic simulation model, considering a range of transmission settings. The approach can be adopted for comparative analyses of the cost effectiveness of different intervention strategies.

Hirth RA, et al. (2000) Willingness to Pay for a Quality-adjusted Life Year: In Search of a Standard *Med Decis Making*; 20:332-342

Cost-benefit analysis (CBA) provides a clear decision rule: undertake an intervention if the monetary value of its benefits exceeds its costs. Reluctance to

characterize health benefits in monetary terms means cost-utility and cost-effectiveness analyses rely on arbitrary standards (e.g., < $50,000 per QALY) to deem a program "cost-effective." No consensus exists regarding the appropriate dollar value per QALY gained upon which to base resource allocation decisions. The authors imply a QALY value from studies and compare this with arbitrary cost-effectiveness thresholds in common use. Converting to US dollars, most value estimates far exceed thresholds used to determine whether an intervention produces an acceptable increase in health benefits in exchange for incremental expenditures.

Olsen JA, Richardson J (1999) Production Gains from Health Care: What should be included in Cost-effectiveness Analyses? *Social Science & Medicine* Vol 49, Issue 1, pp 17-26

This article considers 'indirect benefits' to include in cost effectiveness and cost utility analysis. Relevant issues include: net resource costs of providing health care and costs and benefits society is prepared to consider in its assessment of health services. Any preference for 'equal access for equal need' means production gains may need to be disregarded. The analysis suggests that the magnitude of socially relevant production gains varies between countries as it depends upon differences in patients' potential contributions to the rest of society (tax rates) and the strength of preferences for equity.

c) Labor lost days as a proportion of income

Konradesen F, et al. (1997) Measuring the Economic Cost of Malaria to Households in Sri Lanka *AM J Trop Med Hyg* 56(6):656-60.

The household economic cost of labor days lost due to malaria and other illnesses was estimated in a rural community in Sri Lanka for those of economically-active age. Value was based on actual rural wages. Work days lost amounted to an annual economic loss per household of 6% - 18% of net income. Malaria cases concentrated in the agricultural season. Children, not part of the economically active population, lost 10% of school days due to malaria during high transmission season. These costs should be considered together with direct expenditures incurred by households (e.g. for treatment and travel) and with costs for the service providers in estimating the socioeconomic impact of malaria.

d) Indicator of environmental risk

World Resources Institute (2009) Linking Environment and Health/Environmental Risks to Human Health: New indicators
http://www.wri.org/publication/content/8349

World Resources Institute has developed new environmental health indicators that describe environmental risks to human health. The indicators rank countries according to potential environmental threats to human health. For developing countries, the indicator aggregates measures of environmental risks to human

health from three categories: air, water, and nutrition. The water portion of the indicator includes three variables: two represent potential exposure to poor quality water (i.e., percentage of the population without access to safe water and without adequate sanitation) and one represents exposure to insect-borne diseases (i.e., the percentage of the population with malaria).

e) Human health as bio-indicator of ecologic well-being

Cook A, Jardine A, Weinstein P (2004) Using Human Disease Outbreaks as a Guide to Multilevel Ecosystem Interventions *Environmental Health Perspectives* (commentary) Vol 112, No 11

Human health often depends on environmental variables and is generally subject to widespread and comprehensive surveillance. Compared with other measures, human disease incidence may be one of the most useful and practical bio-indicators to gauge ecologic well-being. Whereas subtle ecosystem disruptions may be identified only after an anomalous increase in human disease detected by routine surveillance, outbreak data on vector-mediated diseases and direct zoonoses can act as a pivotal warning system for ecosystem disruption. Appropriate ecologically-based remediation strategies can be introduced at an earlier stage than if based solely on environmental monitoring thereby reducing the level of "ecosystem distress" as well as resultant disease burden in humans.

5) Measurement challenges linking health and the environment

Rapport DJ (2007) Healthy Ecosystems: An Evolving Paradigm Chapter 30 in The SAGE Handbook of Environment and Society by Orr D, et al. *(*eds*)*, SAGE Publications

Toxic substances, particularly pesticides, bio-accumulate in the food chain and can accumulate enough to place top levels at risk. Less known are the many complex pathways by which human alterations of ecosystems pose public health risks. Among these are changes in the distribution of human pathogens as a result of human-created ecological imbalance. Connections between human health outcomes and the health of ecosystems are complex and not easy to quantify owing to the complexity of the relationship. We need to take into account the capacity of human societies to buffer adverse health effects (through public health and medical services), inherent lags between environmental changes and organism response and the fact that health outcomes are the summation of many influences.

Huynen M, Martens P, De Groot RS (2004) Linkages between Biodiversity Loss and Human Health: a Global Indicator Analysis *Int J Environ Health Res* 14:133–30

The global association between health and biodiversity loss is explored using regression analysis controlling for confounding by socio-economic developments. Indicators include i) for health: life expectancy, DALYs, infant mortality and % low-birthweight babies; ii) for biodiversity: % threatened species, current forest as a % of original forest, % of land highly disturbed by man; and iii) for socio-economic development: health expenditure as % of GNP, % one-year olds immunized, illiteracy and GNP per capita. Neither current forest as a % of original forest or the % of land highly disturbed by human activities had a relationship with any health indicators. The logarithm of the % threatened species, however, showed a positive association with life expectancy and DALYs. While the study did not provide empirical proof of a negative association between loss of biodiversity and human health at the global scale it does not mean that no such relationship exists. Findings could be due to a possible non-linearity of the relationship, lack of appropriate indicators, non-randomness in the sample of countries used and limitations of regression analysis in proving causality.

a) Focus on large-scale changes needed to detect health effects

McMichael AJ, Woodruff RE (**2005)** Detecting the Health Effects of Environmental Change: Scientific and Political Challenge (editorial) *EcoHealth* 2 (1) 1-3

Little detailed knowledge exists about how changes to ecosystem functioning affect human health. The IPCC has not yet identified certain evidence of effects on human health attributable to climate change nor did the MA document many clear examples of adverse effects on human health due to human-induced ecosystem changes. Early evidence of health effects is marginal because changes to system functioning occur over decadal time. Also, most outcomes are multi-factorial in origin making direct causal links difficult. Models help predict human biological and social impacts but for policy makers, future displaced forecasts of adverse health consequences may lack relevance. We should therefore link currently observable adverse health effects of environmental changes with likely future effects of large scale bio-geophysical environmental changes impinging on whole populations.

b) Integrating processes from different scales

Kitron U, et al. **(2006)** Upscale or Downscale: Applications of Fine Scale Remotely Sensed Data to Chagas Disease in Argentina and Schistosomiasis in Kenya *Geospat Health*; 1(1): 49–58
http://www.biomed.emory.edu/PROGRAM_SITES/PBEE/pdf/Kitron_2006_GeoHealth.pdf

Two studies are described where the transmission dynamics and risk of infection were assessed on the micro-scale, starting with households, and then extended gradually to consider several communities and sources for vectors or intermediate hosts. The study specifically addresses how key measures of risk and transmission dynamics may vary with scale and how to integrate processes

occurring at diverse spatial and temporal scales. The authors conclude that spatial heterogeneity on the micro-scale may not be detected using coarse spatial resolution, and conversely, general patterns on the macro-scale may not be detected using fine spatial resolution.

c) Inadequacy of traditional epidemiological measures

i) Measure at population and (eco) system levels

Eisenberg JN, et al. (2007) Environmental Determinants of Infectious Disease: a Framework for Tracking Causal Links and Guiding Public Health Research *Environ Health Perspect* 115:1216–23

The authors present a context in which to examine the environmental change and disease transmission relationship integrating three factors: *a*) environmental change manifests in a complex web of ecologic and social factors that may ultimately impact disease, represented as those more distally versus proximally related to disease; *b*) transmission dynamics of infectious pathogens mediate effects of environmental change on disease; *c*) disease burden is the outcome of the interplay between environmental change and the transmission cycle of a pathogen. Using a matrix formulation the authors express the problem at a systems level going beyond a traditional risk factor analysis as it provides a means to explicitly express the coupling of environmental and disease transmission processes.

Pekkanen J, Pearce N (2001) Environmental Epidemiology: Challenges and Opportunities *Environ Health Perspect* 109:1–5 http://ehpnet1.niehs.nih.gov/docs/2001

Many environmental exposures, some with low relative risk, can be addressed only by comparing populations versus individuals. Ecosystems disruption requires new methods of epidemiologic study design and the authors argue for the reintegration of epidemiology into public health. The involuntary nature of most environmental exposures supports focus at the population and ecosystem levels where interventions are the most appropriate.

ii) Nonlinearity of the relationship

Jozef W, Martens M, McMichael AJ (2002) (eds) Environmental change, climate and health: Issues and research methods, Cambridge University Press

Mainstream epidemiological research methods do not adequately address health impacts arising when ecological and other biophysical processes display nonlinear and feedback-dependent relationships. This book identifies the nature and scope of the problem and explores conceptual and methodological approaches to studying these relationships, providing estimates of health impacts and attendant uncertainties.

d) Sensitivity of traditional population health measures (e.g. life expectancy)

Soskolne CL, Broemling N (2002) Eco-epidemiology: On the Need to Measure Health Effects from Global Change *Global Change & Human Health* Vol 3, No 1

To prevent harm to human health from degrading ecosystems, epidemiologists need indicators sensitive to shifts in health status that parallel these declines. Traditional measures of health (e.g., life expectancy, infant mortality) are intuitively linkable to effects from environmental degradation but do not provide early warning indications of negative ecological impacts on health. Alternatives such as social well-being combine factors with policy relevance (including more sensitive measures) and models of human behaviors that contribute to ecological declines. Epidemiologists must be able to relate health outcomes to eco-regions so that direct comparisons of effect can be made.

Sieswerda LE, et al. (2001) Toward Measuring the Impact of Ecological Disintegrity on Human Health *Epidemiology* Vol 12 No 1, pp 28-32 http://www.jstor.org/stable/3703675

Ecological integrity refers to the ability of environmental life-support systems to sustain themselves in the face of human-induced impacts. A correlational, aggregate-data study design was used to explore whether life expectancy is linked to large-scale declines in ecological integrity. Surrogate integrity and per capita GDP measures (social confounders) were also modeled using linear regression. The relationship between integrity and life expectancy was modest (and direction inconsistent) and disappeared when GDP was controlled. GDP was the major predictor of life expectancy suggesting relations between integrity and health are mediated by socio-economic factors. However, life expectancy may be too insensitive a measure of the effect of ecological integrity on population health.

e) Need for combined measures

Havelaar A (2007) Methodological Choices for Calculating the Disease Burden and Cost-of-illness of Foodborne Zoonoses in European Countries Report No. 07-002 *Med-Vet-Net Network for the Prevention and Control of Zoonoses*

A trend in public health research is the use of integrated metrics to indicate priority areas for action. Infectious diseases typically have several possible health outcomes ranging from acute self-limiting diseases to chronic disabilities or even death. These can be combined in single composite measures such as DALYs or the (monetary) cost-of-illness. Disease burden and cost-of-illness calculations differ depending on methodology. The choice must reflect the decision context of the study and the values that exist in the societies under study.

f) Need to include human values

Rapport DJ, Costanza R, McMichael AJ (1998) Assessing Ecosystem Health *Trends in Ecology & Evolution* Vol 13, Issue 10, pp 397-402

Evaluating ecosystem health in relation to the ecological, economic and human health spheres requires integrating human values with biophysical processes.

g) Displacement of effects in time and space

Campbell-Lendrum D, et al. (2005) Consequences and Options for Human Health Chapter 16 in Ecosystems and Human Well-being: Policy Responses http://www.millenniumassessment.org/documents/document.321.aspx.pdf

Ecosystem disruption damages health through complex pathways. Local conditions exert a strong influence on the nature, extent, and timing of the effects on health. Social adaptations may minimize, displace or postpone them. Many effects of ecosystem disruption on health are displaced either geographically or into the future.

h) Clarification of terms

Vira B, Adams WM (2009) Ecosystem Services and Conservation Strategy: Beware the Silver Bullet C*onservation Letters* Vol 2, Issue 4**,** pp 158 - 162

Despite links between ecosystem services, natural capital and biodiversity, they are not identical. Important analytical distinctions exist between ecosystem service flows and the stock of natural capital that underpins or constitutes them. Ecosystem services result from the interplay of different biological and physical processes across a variety of scales and flows of ecosystem services may be imperfectly related to natural capital stocks. Conservation is concerned with the protection of natural capital stock but also with maintaining the complex web of relationships that characterize biodiversity. Caution is advised when using 'ecosystem services' as a proxy indicator when developing mechanisms for biodiversity conservation; conceptual clarity is essential to harness the potential role that ecosystem service-based interventions can play in mainstreaming conservation issues.