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Biodiversity and Human Health: A Multidisciplinary Approach To Examining the Links

Smithsonian Institution
National Museum of Natural History
Baird Auditorium
10th Street and Constitution Avenue, NW
Washington, DC 20013

Washington, DC

September 14, 2006

Background

The National Center for Environmental Research (NCER) at the U.S. Environmental Protection Agency's (EPA) Office of Research and Development has proposed a joint Ecosystem-Health Research Program to study the links between changes in biodiversity and risks to human health. NCER has a responsibility to undertake exploratory research on emerging scientific issues, and forums are organized for these topical discussions. Studying the relationship between biodiversity and human health is a timely research opportunity. The loss of biodiversity is accelerating while infectious diseases appear to be emerging and reemerging at a faster rate. Research on the links between these two conditions can have an important impact on our view of biodiversity, the services provided by natural ecosystems, and how we manage them.

In co-sponsorship with Yale University's Center for EcoEpidemiology, the Smithsonian Institution, and the World Conservation Union, EPA/NCER is convening this interdisciplinary forum of researchers, practitioners, and decisionmakers in ecology, public health, remote sensing, and the social sciences. We will discuss the state of the science, refine research priorities, and begin discussions on how to integrate existing data into a monitoring and risk-forecasting network that aims to prevent or significantly mitigate risks of human disease and threats to biodiversity around the world.

The forum will consist of presentations on themes related to biodiversity and human health such as 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; valuation of biodiversity for public health; and applications of research to the Global Earth Observation System of Systems (GEOSS). These presentations will be part of an outreach effort to scientists and decisionmakers to stress the importance of the connection between biodiversity and human health and to discuss the state of the science.

The event brings together experts from a variety of disciplines, academia, nongovernmental organizations, and management agencies from the United States and abroad to share expertise and information and to consider new approaches to characterize the relationship between biodiversity and human health.

This forum is part of a series on contemporary issues related to the environment and health sponsored by the Yale Institute for Biospheric Studies Center for EcoEpidemiology.

The initiative on biodiversity and human health is being led by EPA in partnership with the National Oceanic and Atmospheric Administration, the Center for Health Applications of Aerospace Related Technologies at the National Aeronautics and Space Administration's Ames Research Center, and the Smithsonian Institution.

Biodiversity and Human Health: A Multidisciplinary Approach To Examining the Links

September 14, 2006

Executive Summary

Around the world, the loss of biodiversity is accelerating, while infectious diseases appear to be emerging and reemerging at a faster rate. Research on the links between these two conditions can have an important impact on our view of biodiversity, the services provided by natural ecosystems, and how we manage them. In co-sponsorship with Yale University's Center for EcoEpidemiology, the Smithsonian Institution, and the World Conservation Union, EPA's NCER convened an interdisciplinary forum of researchers, practitioners, and decisionmakers in ecology, public health, remote sensing, and the social sciences. The forum was an outreach effort to scientists, decisionmakers, and the public to increase awareness of the connections between biodiversity change and human health. NCER plans to support research to characterize the relationship between biodiversity change and human health and encourage interdisciplinary collaborations, within the United States and internationally, to address these issues.

The public forum consisted of presentations on various topics related to biodiversity and human health, including research on biodiversity decline and increased incidence of infectious diseases, the role of social capital in managing environmental resources, soil biodiversity and human health, protecting biodiversity for potential medicinal value, wildlife trade and risks to biodiversity, valuation of biodiversity related to disease, and potential applications for observing systems to monitor and predict risks to the environment and health. Through a variety of perspectives and disciplines, the forum identified the need for further research to better characterize scientific mechanisms and the anthropogenic stressors that affect them, as well as encouraged interdisciplinary collaboration to address these issues.

Changes in Host Biodiversity and Incidence of Infectious Disease

Empirically based models predict that the loss of host-species diversity results in a greater proportion of ticks infected with the Lyme disease pathogen. This dilution effect predicts lower rates of infection for a particular pathogen in highly diverse communities, where less competent hosts dilute transmission rates. Predator species richness and forest fragmentation were found to be related to the density of infected vectors. Although there is evidence of a dilution effect for other pathogens, such as West Nile virus, it is possible that increasing diversity of competent hosts can provide opportunities for increases in disease transmission. Vector feeding behaviors need to be explored under different conditions of host diversity and density. The regulation of vectors in nature remains an important area of research.

Habitat Alteration and Disease Transmission

An interdisciplinary study on disease transmission among people and primates in Uganda, where forest fragmentation has reduced the biodiversity of plants, vertebrates, and invertebrates, showed an association between forest clearing and the development of gastrointestinal problems in people living nearby. Higher levels of microbes were also found in these disturbed sites, along with increased interspecific disease transmission among primates including people. A working model was developed describing the roles of socioeconomic, cultural, and environmental factors on disease emergence. In Peru, deforestation has been associated with increased malaria transmission. Human biting rates of *Anopheles darlingi,* the most efficient vector of malaria in the Peruvian Amazon, were significantly higher in deforested sites compared to sites with less habitat alteration, independent of population density. Land-use changes can also disrupt the critical roles that soil microbes play as biological control agents, parasites, and predators to moderate outbreaks of disease in water, food, plants, humans, and other animals.

Social Science Perspectives on Biodiversity and Health

A study of risk posed by coastal hazards among villages in Thailand, where mangrove forest fragmentation has degraded the disaster mitigation function of these ecosystems, indicated a relationship between community-based social capital and success in reforestation efforts. Higher levels of social capital indicate greater capacity to take collective action for enhancing coastal ecosystems that leads to reducing risk to human communities. A conceptual model was developed explaining the influences of social capital and humanitarian aid delivery systems on community performance in ecosystem restoration. In Brazil, researchers studied biodiversity valuation in the context of disease regulation. Econometric models of the effects of climate change and deforestation on malaria showed that gross domestic product, investments, and imports decrease with current climate change trends and increase with forest conservation.

Applications of Research for Risk Monitoring and Prediction

A European research program, Emerging Diseases in a Changing European Environment (EDEN), was developed to identify, evaluate, and catalog ecosystems and environmental conditions linked to global change that affect infectious disease transmission over space and time. This cooperative effort integrates research on disease systems that are linked by key activities such as disease modeling, environmental change detection, and biodiversity monitoring with the goal of developing early warning systems. A similar effort is underway to develop a comprehensive and coordinated system of observing systems at the global level to monitor and predict risks to health and the environment. GEOSS is organized under nine Societal Benefit Areas, including conserving biodiversity and understanding the environmental factors that affect human health and well-being. Models have been produced to predict the effects of climate on cholera and reduce disease burden in Bangladeshi villages.

Videos of the presentations are archived at http://www.yale.edu/yibs/biodiversity.html.

Biodiversity and Human Health: A Multidisciplinary Approach To Examining the Links

September 14, 2006

Meeting Summary

OVERVIEW

The U.S. Environmental Protection Agency (EPA) Biodiversity and Human Health: A Multidisciplinary Approach To Examining the Links meeting was held September 14, 2006, in Washington, DC. Co-sponsored by EPA's National Center for Environmental Research (NCER)—part of EPA's Office of Research and Development (ORD)—and Yale University's Center for EcoEpidemiology, the Smithsonian Institution, and the World Conservation Union, the forum explored issues related to changes in biodiversity and risks to human health. Experts from a range of disciplines from academia, nongovernmental organizations (NGOs), and management agencies from the United States and abroad participated, presenting on various themes such as epidemiology and vector ecology; wildlife trade; and the valuation of biodiversity for public health. Approximately 175 individuals attended the meeting, while others in and outside of the United States tuned into the live Webcast. A list of participants is included in the Appendices.

Introduction
Gary Foley, EPA/ORD/NCER

Dr. Gary Foley welcomed the participants and introduced himself as the Director of NCER. He was glad to have the opportunity to be involved with this forum, one that he hopes will present positive challenges for the participants. He then introduced the first speaker Dr. William Farland, the Acting Deputy Assistant Administrator for Science at EPA/ORD. Speaking after Dr. Farland was Dr. Conrad Lautenbacher, Jr., the Under Secretary of Commerce for Oceans and Atmosphere and the Administrator of the National Oceanic and Atmospheric Administration (NOAA).

Welcome and Opening Remarks
William Farland, EPA/ORD

Dr. Farland began by thanking the meeting sponsors—the Yale Center for EcoEpidemiology, the Smithsonian, and the World Conservation Union—for helping EPA orchestrate the meeting. He described the event as a unique opportunity to bring ecological health and human health together. This interdisciplinary approach is the objective of a research program proposed by NCER to examine the links between changes in biodiversity and risks to human health. Taking an interdisciplinary approach, the forum provides the opportunity to share different perspectives on themes related to biodiversity and human health. EPA's research program is focused on determining how anthropogenic drivers of changes in biodiversity directly affect the transmission of human disease and the underlying mechanisms that connect these issues.

Although the idea that biodiversity change and human health might be connected directly is not a new one, it is a topic that needs to be explored further. It is known that biodiversity loss is accelerating. There is a decline occurring in wild populations of vertebrates in terrestrial and aquatic environments. At the same time, there is an emergence or reemergence of infectious diseases. Examining the root causes of disease emergence and spread will assist in prevention and mitigation strategies. This research should be undertaken with the understanding that environmental factors contribute to the diseases and that environmental stewardship may reduce their burden. Also critical is the exploration of the underlying relationship between biodiversity and human health and the development of new tools and approaches. This research has unique characteristics, including its focus on systems where biodiversity change is hypothesized to be an important driver of risks to human health, and its attempt to link Earth observation data to societal benefits related to human health and biodiversity conservation. EPA believes the research is timely and will place the Agency at the forefront of a new field focusing on biodiversity's role in human health and well-being. Key expected outcomes include an increased awareness of the connections between biodiversity and human health; support for research to characterize the relationship between biodiversity change and human health; and new momentum for interdisciplinary collaborations, within the United States and with international partners. Dr. Farland concluded by recognizing two key international collaborators who spoke later in the day: Dr. Stéphane de La Rocque, Project Coordinator for a new project of the European Commission called Emerging Diseases in a Changing European Environment (EDEN); and Dr. José Achache, Director of the Group on Earth Observations (GEO) Secretariat. Dr. Farland added that he was looking forward to dialogue with EPA's international partners, as well as with the forum participants, on the important scientific aspects of the research at hand.

Taking the Pulse of the Planet: A Multi-Disciplinary Approach to Biodiversity and Public Health
Conrad Lautenbacher, Jr., U.S. Navy (Ret.), National Oceanic and Atmospheric Administration

Dr. Lautenbacher thanked Drs. Foley, Farland, and Pongsiri for their efforts in organizing the event and thanked the participants for their attendance. He began with an analogy, mentioning that, on a rainy day in Washington, one can almost see the mold growing beneath one's feet when walking, and it conjures up the image of the area as being a swamp prior to development, with mosquitoes in the vicinity. Although rain is connected to human health and well-being and the planet, it is commonplace and humans do not deal with it on a global level to make any global connections. The foundation of science is observation, and better health policies are needed that are connected to general science. Large-scale observations are required to permit discussions of global level problems. It also is important to work on issues in a connected system because human health is directly dependent on the health of the planet. An example of linking biodiversity and health occurs with coral reefs, upon which millions of people depend for their livelihood. Reefs are an important pharmaceutical source, holding the promise to cure various diseases, such as cancer, HIV/AIDS, and arthritis. It is established that coral reefs are stressed by high water temperatures and light levels, resulting in coral bleaching. Studies are underway and new management tools are being developed to measure and forecast threats to coral reef ecosystems.

Integrated environmental understanding of biodiversity and human health also has facilitated prediction of disease outbreaks. For example, it is known that the incidence of malaria and other vector-borne diseases can change dramatically during extreme weather events related to El Niño. The monitoring of physical, chemical, and biological parameters, and integration of this information into a comprehensive data management system, is the premise for GEOSS, the Global Earth Observation System of Systems. GEOSS involves 65 countries and 43 organizations and has four operating principles to ensure that the system is useful globally. A new GEOSS product in development, GEO-NETCast, will serve as a real-time global data system that will use satellite technology to bring information to the global public health community and many other communities in a user-friendly form. A rudimentary version of the system will be operational in about 1 year and will include biological and medical information that, to date, has not been connected well with environmental information. Integrating the various data sources will facilitate prediction, decisionmaking, response and, ultimately, bring public health benefits. Dr. Lautenbacher concluded by expressing his gratitude for the opportunity to deliver his message and added that Dr. Achache is present and can answer any questions on GEO after his presentation later in the day.

RESEARCH PRESENTATIONS

Dr. Foley introduced Dr. Montira Pongsiri as the moderator for the remainder of the meeting. He commended her efforts as one of the EPA staff members who organized the meeting. Dr. Pongsiri works with Dr. Joe Roman on biodiversity and health at NCER.

Dr. Pongsiri thanked all of the participants and stated that it was a privilege to have Drs. Farland and Lautenbacher open the meeting. Each research presentation in this portion of the forum was followed by a discussion session. A Webcast also was held and recorded; it is archived on the Yale Center for

EcoEpidemiology Web Site at http://www.yale.edu/yibs/biodiversity.html. The Forum presentations also will be accessible from the new EPA Portal on Biodiversity and Health, which was launched on September 13. The URL is http://www.epa.gov/ncer/biodiversity. The Web site will be updated regularly and is intended to serve as a resource for scientific information on biodiversity and health, as well as for learning information on related EPA efforts, activities with partners, and upcoming events.

BIODIVERSITY DECLINE AND RISKS TO HUMAN HEALTH

Biodiversity and the Dilution Effect: The Case of Lyme Disease
Richard Ostfeld, Institute of Ecosystem Studies

Considered one of the emerging infectious diseases alongside such diseases as HIV/AIDS, avian influenza, and SARS, Lyme disease (LD) is a zoonosis occurring primarily in three loci across the United States—the West Coast, upper Midwest, and the Eastern seaboard—with roughly 20,000 cases reported per year. LD is caused by the bacterium *Borrelia burgdorferi* and transmitted by the nymphal stage of the tick *Ixodes scapularis* to vertebrate hosts that act as reservoirs of the pathogen, which is later transmitted to humans. A common, highly permissive, and abundant host for *B. burgdorferi* is the white-footed mouse, *Peromyscus leucopus*. This study examined a proposed model for the effects of vertebrate density on the infection prevalence of LD known as the "dilution effect" model. The model proposes that high host diversity presents the tick population with many opportunities to feed on hosts that are very inefficient in transmitting the LD bacterium. These communities also have greater control on the abundance of white-footed mice via predation and competition. By increasing the number of non-mouse hosts, the ticks take fewer mice meals, thereby reducing tick infestation of mice. These effects of high vertebrate density represent a "dilution effect" of LD on mice. Data were obtained via trapping and netting various mammal and bird hosts, with translocation to the laboratory to determine tick burdens and reservoir competence. The model predicted that, in an intact forest community, about 45 percent of the ticks will be infected; the empirical value was within 1 percent of that prediction. Simulation then was used to dissemble the community, and remove species, in approximately the order in which they are lost by habitat fragmentation. It was shown that increasing loss of host species results in a greater proportion of infected ticks, with the highest proportion (92.1%) for a mice-only community. Whether the density of infected nymphs is influenced by increasing host diversity was examined via 40 trapping sites across three different Northeastern areas. The study found a significant negative correlation between predator species richness and white-footed mouse population density. The study also found that the strongest factor reducing tick burdens on the mice is the increasing abundance of chipmunks, with an average larval burden per mouse decreased by 20 larval ticks as the number of chipmunks increases from 0 to 80.

In examining forest fragmentation and LD risk, the research found that larger forest fragments consistently have more numbers of host species. Smaller forest fragments would experience a loss of vertebrate diversity, leading to poor regulation of the white-footed mice populations. This in turn would lead to increased infection prevalence and high tick density, together increasing LD risk. This model was tested in 14 more forest fragments in Dutchess County, New York, and researchers found a significant negative correlation between fragment size and nymph density, as well as a significant decline in both nymph infection prevalence and density of infected nymphs. On average, small forest fragments had about four to five times higher density of infected nymphs than did larger forest fragments. It is proposed that the dilution effect might be operating by four distinct mechanisms: reducing the abundance of the reservoir; diverting vector meals to less-competent hosts; reducing vector abundance; and reducing the rate of transmission of the pathogen. The next step is to determine whether the dilution effect might apply to other disease systems.

Discussion

Dr. Mustafa Aral asked whether any information has been generated on the effect of the ticks on the lifespan of the host over time or vice versa. Dr. Ostfeld responded that this question has received little attention to date and it is an important one to address to understand the dynamics of LD. Only a few pathologies have been found in relation to the impact of the *Borrelia* infection on hosts, with no evidence that lifespan is reduced and no clinical signs have been found in wildlife hosts. These few observations have been found in domestic hosts, such as dogs and horses, and there has been no known impact on humans. Dr. Ostfeld added the findings have almost certainly had some, if minor, impacts on fitness. The finite instrumentation required to detect the impact of *Borrelia* infection on host populations also likely explains the paucity of information.

A participant asked whether there are counties or communities elsewhere in the world that have used research findings on LD in conjunction with land use planning. Dr. Ostfeld replied that one problem with applying the information is translating it into policy. For instance, the sampling needs to be increased to include more counties and more areas, to increase the confidence of the results. He explained that there is a bit of a disconnect between the notion that fragment size or fragmentation itself has an impact on LD risk and what kind of zoning or other regulations would be implemented. Although it is tempting to assume that the larger the lot, the larger the forest being conserved, this is not necessarily the case. For instance, cluster housing would include very small individual lots but also have a larger tract of forest preserved for communal use.

Dr. Anand Ramanathan asked whether there is a comparison between entomological risk measures and incidence of LD in the human population. Dr. Ostfeld responded that this has not been attempted until fairly recently. He mentioned that certain researchers, including Dr. Durland Fish's group, have addressed this question, but the results have been confounding. For instance, in the area around Connecticut, habitat fragmentation was associated with higher density and infection prevalence in ticks. At the state level, however, fragmentation was associated with lower incidence in human populations. The next step, Dr. Ostfeld explained, is to integrate the entomological risks with human components of risk. Thus, a relationship can be determined from observations of people who live in highly fragmented landscapes or those who do not venture into the woods. Good public health outcomes will rely on integrating entomological risk with human knowledge, attitudes, and behaviors with respect to LD.

Avian Diversity and West Nile Virus Risk

Vanessa Ezenwa, University of Montana

West Nile virus (WNV) is a vector-borne zoonotic infectious disease that has only recently emerged in the United States. Transmitted by mosquitoes, WNV can infect incidental hosts, including horses, reptiles, and humans, in addition to wild birds, which are the main reservoir host for the virus. WNV was first detected in the summer of 1999 in New York City, New York, and has since spread from the East Coast to the West Coast over a 5-year period. WNV distribution depends on having suitable host, environmental, and vector traits, including density, diversity, and physiology; climate and habitat; and density, diversity, and behavior, respectively. This study examined whether patterns of WNV infection in mosquitoes are explained by differences in avian diversity and whether this diversity can influence human WNV disease risk. A field study was undertaken to address the first question and involved weekly mosquito collection and analysis for WNV and infection rate, from a series of six sites in St. Tammany Parish, Louisiana. Bird species richness and abundance were estimated using avian counts. The study predicted that higher non-passerine species richness is associated with lower mosquito infection rates and that higher passerine species richness is associated with higher mosquito infection rates. The results supported the first prediction, demonstrating that non-passerine species appear to be functioning as dilution hosts for WNV, possibly by decreasing contact rates between suitable WNV hosts and vectors. To test the relationship between avian diversity and human disease incidence, a comparative study was undertaken Louisiana-wide, including human cases reported yearly since 2002, with 41 counties with cases in 2002 and 33 counties with cases in 2003. Four predictor variables were examined: passerine species richness, non-passerine species richness, human density, and county area. This study found that non-passerine species richness was significantly negatively correlated with both mosquito infection rates and human disease incidence. In contrast, passerine species richness was not correlated with either human or mosquito infections. These findings suggest that bird diversity may play a critical role in moderating human WNV disease risk. Further work will examine the mechanisms underlying the observed patterns.

Discussion

Dr. David Blockstein asked whether future studies will examine the role of landscape types and try to parse that out, given that nonforested habitats tend to have a higher proportion of non-passerines relative to forested habitats. Dr. Ezenwa replied that the study has found an interesting wetland effect, likely because the team is working primarily in a wetland area and, therefore, a large proportion of the sites tended to be wetlands. The results showed that wetlands had a strong negative association with WNV prevalence. The group tried to parse this result out to determine how wetland area was influencing mosquito infection rates. Several factors were assessed, including how wetland area influences the density of mosquitoes, how it influences the abundance of different host species, and how it influences the relative composition of host species. The research revealed that wetland area influences the composition of bird species, which strongly influences vector infection. The team believes, therefore, that habitat would display a strong role by influencing the relative interactions between different host species in the habitat.

Dr. Sarah Randolph commented that she is a little concerned about the slightly crude measure of host diversity and bird diversity, especially given the low heterogeneity in the contact between vectors and their hosts. She asked whether or not the team has taken account of the type of results that have emerged from past research on the disproportionate feeding by mosquitoes on certain host species that are apparently rather less common in the habitat. Dr. Randolph suggested that it would be beneficial to focus on other, more specific traits, rather than just species abundance, to produce more accurate results. Dr. Ezenwa agreed that there is enormous heterogeneity in the way in which different vectors feed on the host species and that finer scale analyses are needed. She added that her study was a preliminary analysis to determine whether any pattern could be found, to document effects observed, and to examine in more detail how characteristics such as bird diversity and density affect differences in vector feeding behavior, and how that relates to vector infection patterns. Dr. Ezenwa noted that with a system such as WNV, which involves multiple hosts and multiple vectors simultaneously, teasing apart effects is challenging.

Dr. Gregory Glass asked whether the team has conducted blood meal analysis on the mosquitoes. Dr. Ezenwa responded that her team has not done any work so far on mosquito blood meal analysis, but there are plans to do so in the future.

Dr. Aral asked whether the impact of the climate effect for 2002/2003 on the results was examined. Dr. Ezenwa responded that, because the study encompassed only 2 years, and the sample size was insufficient, it was difficult to assess the influence of climate change. In addition, the subsequent years have had less WNV incidence in Louisiana, so climate level analysis would again be difficult with insufficient data. She added that her team looks forward to analyzing the effect of climate change with a larger sample size.

Dr. Pongsiri asked whether mosquitoes appear to have a preference for non-passerine species or whether the results are more attributable to host availability/abundance. Dr. Ezenwa responded that the results presented were based on the assumption that vectors feed on hosts in the proportions in which they occur in the habitat. This, she added, is probably not the case. Research on vector feeding preferences must be combined with work on species abundance and diversity to better understand the broad patterns that have emerged.

DISEASE EMERGENCE IN TERRESTRIAL AND MARINE ENVIRONMENTS

Disease Emergence in Terrestrial and Marine Environments
Rita Colwell, University of Maryland

Drawing insight from many contexts, the study of infectious disease in the 21st century must be viewed from a global perspective and with an improved understanding of epidemiology. The global scale of research in this century is unprecedented; it is multi- and interdisciplinary, and scientific questions cross national borders. Diseases of epidemic scale include cholera, caused by the bacterium *Vibrio cholerae*. The bacterium is associated with a copepod, and the sequence of zooplankton blooms following phytoplankton blooms has permitted the use of remote sensing to understand the relationship between sea surface temperature and cholera epidemics. Seasonality is a characteristic of almost every infectious disease, and every infectious disease has an environmental origin. The El Niño is a predictor of cholera. Research for the last 8 years in Bangladesh has involved data collection on environmental parameters, including pH, temperature, salinity, chlorophyll, and plankton populations and, in combination with clinical and remote sensing data, has made possible the prediction of the geographic location and intensity of cholera epidemics. In August 2004, a study tested whether cholera rates could be predicted from the previous months; the researchers predicted 24 cases per 1,000 people, and the actual number was 25.8. Other work in Bangladesh has focused on the application value of knowledge on the environmental cycle of cholera, to help humans directly. Researchers have found that removal of the plankton from the waters could reduce the level of cholera in the villages. A 3-year study was undertaken to examine the efficacy of sari cloth filtration in reducing the number of cholera cases. It was found that if a sari cloth was folded five or six times, it could reduce the incidence of cholera by 50 percent. Old cloths are better sieves than newer cloths because the former have more fraying and therefore greater surface area for capturing the microbes. An ongoing study is now being completed. A survey of the villagers in Bangladesh 3 years later found that 60 to 70 percent of the people were employing sari cloth filtration of their water. The hope is to introduce the technique to Africa, where civil unrest has resulted in a breakdown of human cleansing systems and where cholera is especially prevalent.

Discussion

Dr. Linda Stathoplos asked whether the cholera prediction model currently is operational, and if not, what would be needed to implement the model. Dr. Colwell responded that the model can be applied to other diseases and her group is working on these applications. She emphasized that a very important next step will be to feed biological data into the climate models. Dr. Stathoplos then asked whether the predictions will be posted on the Web. Dr. Colwell responded that her group will work with the University of Maryland and other colleagues.

Emergence of Tick-Borne Pathogens in the Northeast United States
Durland Fish, Yale University

The prevalence of tick-borne pathogens has been increasing in the Northeastern United States over the past several decades. In this region, seven tick-borne pathogens are found that are capable of infecting humans with such diseases as LD, human anaplasmosis, babesiosis, and tick-borne typhus. Several key characteristics of ticks make them excellent vectors of disease agents: zoophilic feeding behavior, prolonged host contact, feeding for up to 7 days; pharmacologic saliva; and high pathogen prevalence. It was the changing of landscape from open farmland to a forested environment, along with the introduction of deer, that resulted in the emergence of LD in the 1970s in the Northeast United States, which now is quite strongly infected by *I. scapularis*. A study in Westchester County, New York, in 1990 found a human-biting rate of 20.4 ticks per 100 persons per year. Extrapolating this figure over 10 states with the highest LD incidence gives approximately 5 million tick bites per year. First diagnosed in 1987, human anaplasmosis is caused by a bacterium that is transmitted by *I. scapularis*. The microbe has several reservoir species, including raccoons, squirrels, and birds. Another disease, babesiosis, also has *I. scapularis* as the vector, but has just the white-footed mouse as its reservoir species. This disease was discovered in 1970, and it has since then spread from east to west across Connecticut. Powassan virus is transmitted by another species of tick, *I. cookei*, and its reservoir species is mustelids. The virus also has been shown to be transmittable by *I. scapularis*. The first case of human infection for this virus was diagnosed in 1958 in Ontario, Canada. Another example of a mammal reservoir of disease is the fisher, which became extinct in 1900 in the mid-Atlantic States. With positive reintroductions in Pennsylvania and West Virginia, the animal now has reached pest status in Connecticut. The fisher is a possible reservoir for moving the powassan virus. In the case of *B. burgdorferi* and *I. scapularis*-borne pathogens, there is evidence of a dilution effect. The addition of other hosts, however, provides the opportunity for a pollution effect because of the trading of a reduction in LD for an increase in other tick-borne diseases. It has been shown that multiple pathogens can occur on ticks, which complicate the diagnosis of disease. Caution must be exercised when interpreting relationships between tick-borne paths and biodiversity, in terms of the recommendations or policy concerning public health and biodiversity relationships.

Discussion

Dr. A. Marm Kilpatrick asked whether the various diseases caused by environmental tick diseases rise to the same level of incidence as LD. Dr. Fish responded that babesiosis and anaplasmosis were introduced into the same region as LD, and that there is potential for spread of powassan virus. He added that environmental change in the Northeast—such as reforestation and succession—might be resulting in a reduction in the cases in risk groups, because there are more woods and more edge.

Dr. Geoff Patton asked about the predators of ticks. Dr. Fish responded that the main source of predation is hosts. He added that a paper published in *The Auk* in the late 1980s claimed that guinea colonies ate ticks. Part of the problem is that only a handful of studies have assessed the biological control of tick populations. It is important, Dr. Fish emphasized, to understand how tick populations are regulated.

Dr. Roman asked about the result of adding high-level predators, such as the introduction of wolves into Yellowstone National Park, on transmission of disease. Dr. Fish responded that, in the case of deer, once the tick populations are established, the deer must be removed before the tick population will crash.

NATURAL HAZARDS AND COASTAL BIODIVERSITY

The Role of Coastal Ecosystem Degradation in Tsunami Damage
Phil Berke, University of North Carolina

A study was conducted to examine the extent of ecosystem damage on the Andaman coast of Thailand following the tsunami of 2004. The research focused on Ranong province, because it is one of the world's great coastal ecosystems and it sustained rather severe impacts from the tsunami. To examine the relationship between coastal ecosystem degradation and the vulnerability of the coastal communities, various sites of damage were assessed at comparable heights and distances from the open coast, using remote sensing analysis as well as field work to collect data. The study also had a social science phase that examined community performance in mangrove forest conservation and the influence of social capital on performance. Throughout the world, mangroves are being lost to urban development and aquaculture. Six villages were chosen based on various criteria, such as sustained damage and presence of mangroves, and key local leaders were interviewed in those locations. Preliminary findings revealed wide variation in the adoption and implementation of mangrove conservation practices, ranging from clear rules and standards for tree cutting, replanting programs, parasite removal, inspection, and monitoring systems in place. In villages where the performance in conservation was high, there was a high level of social capital, with well-established norms in place oriented around the fishing way of life. In these villages, the social capital was activated when external organizations took a bottom-up approach in communication with local people. In contrast, performance in conservation dropped during top-down aid delivery, when external organizations denied grassroots-level networks to respond to local conservation needs; in such cases, houses were designed and built by external authorities. Preliminary conclusions include the need to develop cross-domain models founded on science-based relationships, develop more rigorous models of causes and impacts of social capital, and initiate community demonstration projects for ecosystem management and public health. These projects can aim to strengthen networks; develop leadership capacity; create frameworks to challenge assumptions and motivate action; provide technical resources; and create clearinghouses for networks and contacts.

Discussion

A participant noted that social communities, when more complex, appear to be more resilient, which is an attribute of biological communities of increasing complexity. Is this a reasonable observation? Dr. Berke agreed with that statement. The number of networks and their diversity will influence the strength of bonding within communities.

SOILS, BIODIVERSITY, AND LINKS TO HUMAN HEALTH

Soils, Biodiversity, and Links to Human Health
Diana Wall, Colorado State University

Soil organisms play a central role as causal agents of human disease on a global scale. In 2002, for instance, the World Health Organization estimated a total of more than 6 million deaths from soil-borne pathogens. Categories of soil-borne diseases include viruses, bacteria, protozoa, fungi, and helminthes. For fungi alone, more than 300 out of approximately 100,000 species cause disease. The soil habitat of fauna and flora is shaped by various factors, including geology, climate, and vegetation type. Also variable is the biodiversity present within soils: one gram contains billions of bacteria, down to the hundreds of nematodes. Among nematodes, only about 15 percent are animal or human parasites. In some cases, groups are endemic only to soils, such as the Chilopoda. Most soil species are involved in decomposition processes and, when disturbed, these species can go into a parasitic or pathogen phase. These species also have other jobs, such as providing ecosystem services, including the provision of essential nutrients for biota; decay, detoxification, and purification of water; and prevention of soil erosion and contribution to sediment stability. In some cultures, soil microbes serve as a food source. The most critical role of soil microbes, however, is serving as biological control agents, parasites, pathogens, and predators of other organisms in soil to moderate disease outbreak in water, food, plants, humans, and other animals. An example of soil disturbance is occurring in sub-Saharan Africa, where fields are continually farmed and the scavenging of vegetation and dung deplete soil nutrients. Land degradation results in increased dispersal of microbes and invertebrates. Thus, the soil food web structure becomes disrupted as predators and parasites are removed. This habitat change decreases soil animal diversity. These various soil-borne pathogens can be classified into four types: permanent, periodic, transient, and incidental. An example of a permanent resident-caused disease, cocciodiomycosis, is caused by the inhalation of airborne fungal spores. As with other microbes, soil disturbance increases distribution of the disease agent, *Coccidioides immitis*. Long-term climate fluctuations, such as wind erosion, can affect the growth and distribution of soil-borne pathogens, producing escalating effects on human health in the future. The long-term climate fluctuations that affect growth and distribution of soil-borne pathogens will increasingly affect human health in the future. A systems approach will be needed to understand the relationships between soil, biodiversity, and incidence of human disease.

Discussion

Dr. Pongsiri asked whether anything is known about the genetic diversity of the soil-borne pathogens. Dr. Wall responded that more is known about the genetic diversity of pathogens of economic crops on which humans rely for food, than is known about the soil-borne pathogens of humans.

ENVIRONMENTAL CHANGE AND DISEASE RISK

Biodiversity Loss and the Ecology of Infectious Disease Transmission Among People, Primates, and Domestic Animals in Kibale National Park, Uganda
Tony Goldberg, University of Illinois

A disproportionate number of many human emerging infectious diseases (EIDs), such as HIV/AIDS, yellow fever, and Ebola, come from nonhuman primates. Contributing to this emergence is the fact that humans and nonhumans share habitats and have similar physiologies. Anthropogenic disturbance is altering primate habitats radically. The Kibale EcoHealth Project was initiated 3 years ago to determine how disturbance affects rates and patterns of disease transmission between primates and people; to understand how biodiversity loss affects those rates and patterns and reduces human health; and to improve human health and primate conservation. The study area was located in Kibale National Park, Uganda, an area of high primate biodiversity. The forest in Kibale is fragmented but contains areas of undisturbed, pristine rainforest vegetation. Outside the forest lie remnant forest fragments that are home to primates and that are used by humans. This forest fragmentation has been shown to reduce the biodiversity of plants, vertebrates, and invertebrates in the forest. For instance, 12 primate species live within the protected areas of the park;

however, only 3 species are found outside the park property. The study involved the collection of observational data on the primates; health and survey information from people living around the impacted areas; landscape data that characterize land use habitat and changes over time in the landscape; and pathogen data, including molecular techniques, to infer transmission. A human health survey conducted in 2004-2006 included 477 people and revealed an association between clearing forests and the development of gastrointestinal (GI) problems. The land use data involved multiple scales, using remote sensing and ground survey data. For the pathogen data, the GI pathogens were transmitted via fecal-oral, environment, and waterborne routes. The research has revealed significantly higher levels of microbes in forest fragments versus in undisturbed or livestock areas. The study also found significant interspecific disease transmission involving the exchange of bacteria between chimpanzees and people employed in chimpanzee research and tourism, relative to people from local villages. In addition, a significant proportion of people (80%) was found to have antibiotic resistance to *Escherichia coli* in three Kibale forest fragments, even though these people have very restricted access to health care. There is evidence of movement of this resistance from people to domestic animals and primates in the fragments and undisturbed fragments. Specifically, the study has identified three integrons that move between human and animal bacteria in a Kibale forest fragment. A working model has been developed that takes into account key factors that lead to disease emergence and reductions in health, including the socioeconomic and cultural factors that resulted in the initial forest fragmentation.

Discussion

Dr. Roman asked whether there are any comparable studies ongoing, specifically in South America or Central America. Dr. Goldberg responded that people are aware that there are primates in South and Central America and are interested in the transmission of infectious disease to people and primates. He added that there has been a history of study regarding yellow fever between people and primates in Central America. To Dr. Goldberg’s knowledge, however, there are no other studies that incorporate longitudinal data on human health, primate behavior, changes in the landscapes, and changes in the demographics of those species.

Dr. Pongsiri asked whether the study has examined the effects of habitat perturbation such as fragmentation and its associated stresses (e.g., loss of food source) on the loss of immunity in primates. Dr. Goldberg responded that there are no direct measures of immunity, but that his collaborator at McGill University in Montreal, Dr. Tom Chapman, has been studying fecal cortisol levels as a rough index of stress. This work has found that cortisol levels do seem to respond to habitat disturbance, with higher cortisol levels found in primates living in edge habitat fragments than in those living elsewhere. A confounding factor is nutrition, however, because the nutritional resources of the animals are much lower in the fragments than in the main forest. Thus, it is unclear whether the direct effects are nutrition-related or due to other stresses. It is important to note that the human populations living around the fragments are highly immunocompromised by a high prevalence of HIV/AIDS. The presence of the immunocompromised people living in close proximity to the stressed nonhuman primates, exchanging pathogens with them, creates a hotspot for emerging infectious disease.

Dr. Judy Oglethorpe pointed out that, in addition to impacts of environmental change on human health, human health can have impacts on the environment. For instance, the local impacts of HIV/AIDS in Africa change the dynamics of resource use. When the main breadwinner is lost, more hunting and fishing and other sustained exploitation of natural resources occurs to provide sustenance for families. Dr. Goldberg responded that this is exactly what is seen in his team’s study area. He explained that the relationship between biodiversity and human health is a two-way street. Many changes that are seen in the use of a region seem to go along with interactive changes that might qualify infections such as HIV and malaria. Therefore, it is very likely that habitat diversity can function to affect human health and human health can function to affect biodiversity.

Dr. Subhrendu Pattanayak inquired whether people were asked in the household survey if they recognized that the changes they are making to the landscape have health consequences for them and may increase transmission of disease. Dr. Goldberg explained that these are extremely impoverished communities, most with extremely low degrees of education. These people are not very aware of the linkages between land use change and disease. He added that the Kibale project has excellent relations with the local and regional government and NGOs in Uganda, and is building on more than 30 years of research on primate ecology and biodiversity. Once the team can identify the risk factors that lead to the reduction of human health as a result of biodiversity loss, this will be a prime position in which to affect change.

Environmental Change and Disease Risk
Gregory Glass, Johns Hopkins University

Research was conducted to assess the effect of deforestation on human-biting rate by a particular vector of malaria, *Anopheles darlingi*, in the Amazonian region of Peru. The study area is located on the Amazon River in Iquitos, a relatively isolated port city on the Amazon. A global elimination of malaria was begun toward the end of World War II and into the 1950s and 1960s. Over time, various malaria surveys were undertaken, and by 1991, *A. darlingi* was no longer detected. In the early 1990s, the human population in Iquitos began to increase and associated with this was habitat change and subsequent incidence of malaria. By 1997, 54,000 malaria cases were reported. The present study used satellite imagery to identify land cover and classified the landscape into nine categories. Mosquitoes were collected from humans performing catches during a 6-hour period through the night. The data were linked with the land cover classification information to determine the locations in which *A. darlingi* was more likely to bite people. The results revealed that bites were more likely in regions of reduced forestation. The study area had about 14 different species of *Anopheles*. The highest abundance of *Anopheles* was in the ecotonal regions, where the land classes are much less distinct. *A. darlingi* is most abundant in areas that tend to be deforested. Increasing forest cover is related to a reduction in mosquito biting rate, whereas less forest cover is associated with a higher biting rate. Dr. Glass outlined various challenges that face biodiversity studies. For one, most biodiversity studies have not been rigorously designed to test theory. Also, many of the studies have failed to note whether methodology ever accounts for the observed patterns. Issues also abound in relation to study design. For example, the presence of humans is an effect modifier for examining the effect of biodiversity reduction on disease risk. In addition, it is important to understand what the surrogates of human disease risk measure. Another challenge is the existence of preconceptions regarding zooprophylaxis, which is the intentional increase in biodiversity by introducing other animals to produce a dilution effect and reduce the risk of human malaria. When vectors are anthropophylic, the strategy of bringing in other animals will not work because these vectors prefer to feed on humans and, therefore, will increase human malaria risk. Zoophyllic vectors might have the potential to produce zooprophylaxis; however, introducing alternative hosts might actually increase the risk for transmission to humans, as some studies have shown. It is of interest to determine what disease systems are likely to lead to improved human health by preserving biodiversity.

Discussion

Dr. Fish commented that vector diversity may influence the risk of malaria transmission, adding that it is possible that not all of the 14 *Anopheles* mosquitoes found in the Iquitos region will become pathogen vectors. Would increasing *Anopheles* diversity as opposed to dominance by the same species help to reduce the burden? Dr. Glass responded that this is a good point, and that one of the challenges of the study was that the resources were not available to determine how many of the species were infectious. Generally, the species mentioned are considered to be potentially efficient vectors of malaria and there are certain species in this group that appear to be relatively inefficient hosts. Manipulating the community structure can help to identify ways to maximize the abundance of some of these less-efficient vectors.

Regarding the quotation by Frederick Bang with which Dr. Glass opened his presentation ("… we have gradually been forced to recognize that the various encephalitides … cannot be eradicated unless we cover the surface of the country with cement."), Dr. Ostfeld commented that the study discussed diversity as though a linear relationship exists between diversity and a health impact, such as risk of infectious disease. Paving the world will destroy the diversity and eradicate its associated diseases. Dr. Ostfeld asked whether the shape of the curve that relates diversity to disease should be reconsidered in order to increase the sophistication of the analysis. In many of the disease systems, there may be a threshold level of diversity, he explained, often a low level, which is needed for a disease to exist in the first place. Beyond that threshold, however, increasing diversity might reduce the burden of disease in some of the systems. Dr. Glass responded that he agrees that this is exactly the issue. Often, an understanding of the dynamics of the systems is lacking.

INTERNATIONAL PERSPECTIVE: RESEARCH ON ENVIRONMENTAL CHANGE AND EMERGING HUMAN DISEASES

Integrated Project, 6th PCRDT
Stéphane de La Rocque, Emerging Diseases in a Changing European Environment
Sarah Randolph, University of Oxford

Stéphane de La Rocque

The EDEN project is an ongoing integrated project of the European Commission. The aim is to identify, evaluate, and catalog European ecosystems and environmental conditions linked to global change and that can influence the spatial and temporal distribution and the dynamics of pathogenic agents. Involving 48 partners in 25 countries, the project has to take a coordinated European approach. The EDEN strategy is to focus on some key indicator diseases that have a strong link with the environment, are currently at risk of reemerging or emerging or spreading, and are representative of a wide geographical range and of epidemiological processes involved in emergence. The diseases include tick-borne diseases, rodent-borne diseases, leishmaniasis, WNV, and malaria. The sub-projects are linked together with various integrative activities that include disease modeling, low-resolution spatial modeling, environmental change detection, biodiversity monitoring, and data management. The strategy will involve learning from the past, explaining the present, and predicting the future, through the development of disease monitoring and early warning systems.

Sarah Randolph

A case study on tick-borne diseases is seeking explanations of past patterns to predict the future. Of all the vector-borne pathogens in Europe, those transmitted by ticks (*I. ricinus*) are the most widespread. This offers a perfect case study of the diverse impact of humans, and direct and indirect (human-induced environmental change) impact on zoonotic risk. The focus is on tick-borne encephalitis (TBE) virus because it has the best spatial and temporal records. It already is possible to explain and predict the distribution of TBE in Europe; now, the goal is to try to account for changing incidence. There are some highly geographical patterns of change between countries in the recorded annual cases of TBE. For instance, in Sweden, there was a stepwise increase in incidence in the early 1980s; in Western Europe, a much more gradual emergence of infection occurred. An analogy to account for the patterns observed is that zoonoses are like an iceberg—their wildlife cycles are largely hidden beneath the surface. Also, their exposure varies in time and space, and the incidence in humans depends on two aspects: the bulk of the iceberg (transmission potential) and the relative exposure (human contact rates). TBE is less widespread and prevalent than LD because it has a lower transmission potential (smaller bulk), but the same relative exposure to humans via the same ticks. Is this emergence of TBE due to the increase in the bulk, which could be thought of as biological factors, or is it due to increase in relative exposure, which can be considered human factors? To answer that question, data have been collected from 1970 to the present from national archives on disease incidence, environment, ticks, hosts, and humans. These data are being collected and analyzed to produce explanations and predictive models. New field work has begun to monitor tick stages at four to six sites per country across Europe to reveal tick population dynamics. Overall, it is obvious that the relationship between biodiversity and risk of zoonotic infection is complex and cannot be described with a simple generic model. More plausibly, the upsurge of TBE has been caused by biological (abiotic and biotic) and nonbiological factors acting independently but synergistically. For instance, there is evidence in the three Baltic states that there are independent but indirectly linked changes in relevant factors acting synergistically to increase TBE incidence. The extreme spatiotemporal heterogeneity in upsurge of TBE could be the result of a differential balance of each factor operating in each place.

BIODIVERSITY AND MEDICINES

Mother Nature's Pharmacopoeia
David Newman, National Cancer Institute

Humans and animals have relied on plants as sources of medication for thousands of years, starting with the use of the opium poppy—the first "drug substance"—more than 4,500 years ago. Examples of other plant-derived drugs include analgesics, a cardiotonic, and drugs to treat malaria. Plant-derived products in cancer include Taxol, which revolutionized the treatment of breast cancer and is derived from the yew tree, and *Vinca* alkaloids, which revolutionized the treatment of childhood leukemia. Two other plant-derived cancer products are camptothecin and podophyllotoxin. Of these four major drug compounds, three are derived from plants that have a fungal epiphyte. The dolastatins and its derivatives are derived from a compound that has been isolated from the cyanophyte on which the sea hare *Dolabella auricularia* grazes. The drug Lipitor resulted from the discovery of a simple compound from a fungal permutation. Another medicinal compound, a 25-amino acid peptide, has originated from the cone snail, is 50 times more active than morphine, has no addictive potential, and was approved in December 2004 for pain medication treatment. In the case of two songbird species (*Pitohui dichrous* and *Ifrita kowaldi*), located approximately 2,000 kilometers apart from one another in New Guinea, diet controls whether or not they harbor toxic alkaloids. These two birds contain the same toxic batrachotoxin alkaloids; the source of these compounds is believed to originate from a tiny melyrid beetle, upon which the birds feed. Insects also can harbor beneficial compounds, such as the range of microbes in their gut flora that produce potential antibiotics and other bioactive agents. For instance, secretions from the termite *Nasutitermes triodiae* are antibacterial. Protecting against biodiversity loss will ensure that possibilities for future discoveries of important compounds and materials from microbes and their hosts also are protected.

The "Plants and People of Micronesia" Project: Perspectives in Understanding the Relationship of Integrative Medicine, Traditional Knowledge and Biodiversity
Roberta Lee, Continuum Center for Health and Healing

Traditional medicine comprises the use of a wide range of modalities and therapies used by traditional cultures for health care treatment such as ayurveda, acupuncture/Chinese medicine, and Native American practices. In the United States, such practices tend to be characterized as alternative treatments. The prevalence of complementary and alternative medicine (CAM) has increased over time. One study from 2004 found that 62 percent of 10,000 U.S. adults used CAM over a 12-month period. To address a significant gap in medical education, the first program in integrative medicine was founded in 1997 at the University of Arizona School of Medicine for postdoctoral medicine faculty to begin to learn about the use of botanicals and the efficacy of compounds used in acupuncture and other alternative treatments. There is now a national organization, the Consortium of Academic Health Centers for Integrative Medicine, which comprises 32 medical institutions, representing 20 percent of all U.S. medical schools. Integrative medicine provides the platform to bring together traditional and alternative medical practices with allopathic medicine. The field is patient-centered, recognizing that states of the mind are equally as important as states of the body in promoting health. Also, it is prevention-oriented but evidence-based. At the Center for Health and Healing in New York, New York, a team of 9 physicians and 11 alternative practitioners work together and follow a model of pluralism that fosters tolerance and integration of biomedicine and CAM. In developing countries, 80 percent of the population uses indigenous health care practitioners for primary care. One project that has been tracking the usage of CAM abroad is the Plants and People of Micronesia Project, which has been ongoing since 1998 in Pohnpei, an island in the Eastern Caroline Islands. The study is tasked with documenting ethnobotanical and ethnomedical practices, and looking at the transfer of traditional knowledge from parents and grandparents to youth. Thus far, information has been gathered on about 30 percent of the local and introduced flora. An example of a traditional use of a botanical in Pohnpei is the use of *Morinda citrifoli* in handicrafts, treatment of infection and wounds, parasites, men's health, postpartum conditions, and rheumatism. Traditional varieties of plants also are used as foods. A current project is compiling information on traditional Micronesian plant use to develop the Primary Health Care Manual. The manual contains basic medical information, organized into chapters by specific conditions. Future applications of the Primary Health Care Manual could help create a more sustainable health system in Pohnpei that nurtures communication between the health care providers, traditional healers, and patients. The manual will also be used in the Ethnomedicine Fellowship Training Program, which is being developed to train physicians in Pohnpei and Palau on traditional plant use in primary health care.

Discussion

Dr. Newman noted that once information is published, it is considered prior art. Thus, the information mentioned in the manual, if intended for use in the development of a product, would have to fall under a use patent. Dr. Lee responded that the intellectual property can be an entire symposium topic unto itself. One of the most important aspects of obtaining the plant information is to attribute that knowledge to the host on the island. Dr. Newman commented again that this issue has arisen in other countries, and once that material becomes published, the information automatically eliminates any patent possibilities because it is then considered prior art.

Dr. Graham Hickling observed that many of the environmental degradation problems are generating health problems in indigenous societies, but many of the peoples in these places do not take practical measures (e.g., filtering water). Yet, these societies house a wealth of information on ethnomedicine. Dr. Lee responded that one hope is for the Primary Health Care Manual to bring some of that common sense knowledge into the detailed knowledge of the ethnobotanical practices.

APPLICATIONS TO THE GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS

GEOSS: A Global Earth Observation System of Systems for Science and Informed Decisions and Actions

José Achache, Group on Earth Observations

The Earth is a complex system of systems, and data are required from multiple observation networks and systems. Specifically, there is a need for a system that provides access to all Earth observation data in standard interoperable formats. The intergovernmental Group on Earth Observations (GEO) comprises 65 countries, the European Commission, and 43 participating organizations. The goal of GEO is to build a Global Earth Observation System of Systems (GEOSS) over the next 10 years, to provide a comprehensive, coordinated, and sustained system of observing systems. The database system will be used by a range of science communities and will integrate various systems, including space-, air-, cryosphere, land-, and ocean-based systems. An example of the application of integration of data and systems is the prediction of hantavirus risk from Landsat imagery over time. A user-driven process, GEO aims to improve and coordinate the observation systems, provide easier and more open data access, foster use through science and applications and, ultimately, answer society’s need for informed decisionmaking. Current work is focusing on the prediction capabilities of when and where the next outbreaks of diseases such as malaria and cholera are likely to happen using advanced earth observations of weather, climate, drought, and air quality. A next step will be to understand how to manage biodiversity in ecosystems so that services they provide could lessen and possibly prevent disease outbreaks. The plan for GEOSS is to serve nine Societal Benefit Areas: reduction and prevention of disasters, human health and epidemiology, energy management, climate change, water management, weather forecasting, ecosystems, agriculture, and biodiversity. GEO will engage a wide range of actors to move observations toward socioeconomic benefits. Among the necessary components will be Earth observations, decision support tools development, Earth scientists, public and private information, and officials, advocacy groups, and the public. These components are represented by the umbrella concept of a GEOSS Users Community of Practice. A voluntary process, GEO will foster international cooperation and synergies and will depend on the goodwill of its members and participating organizations. The greatest challenge will be in achieving the final stage of disseminating information to reach citizens so that they can benefit from the early warning systems to prevent disease outbreaks and natural disasters. The architecture of GEOSS will be finalized before the end of this year.

Discussion

Dr. Aral commented that GEO is a primary and necessary organization and that many uses will be found for the database, which is being assembled. Is there any group in GEO that is going to examine historical data, put it together, and make that available online? Dr. Achache responded that data archiving is underway and many datasets are already archived. Dr. Aral added that his concern is regarding historical data that goes back thousands of years in the Chinese, Japanese, and Indian archives. Will these be included in the archive? Dr. Achache responded that there is no initiative for this immediately. It is likely that many organizations and other countries will be pleased to get together and coordinate archiving historical and prehistorical data.

Dr. Berke asked whether the organization plans to study the socioeconomic dimension in terms of data collection and to spatially portray those kinds of databases. For instance, in a pending disaster, there could be good observations of exposure to a tsunami, earthquake, or perhaps a disease, but because of the social characteristics or features of different ethnic groups, the vulnerabilities of human health exposure to the event are not going to be equivalent. Dr. Achache responded that GEO is initiating a study not only on socioeconomic benefits, but also covering an aspect that is relevant to decisionmakers—a cost-benefit analysis of using GEOSS versus not having the good observations and science.

WILDLIFE TRADE AND RISKS TO BIODIVERSITY AND HEALTH

The Trade in Wild Animals: A Threat to the Health of People, Domestic Animals, and Wildlife
Robert Cook, Wildlife Conservation Society

Established as the New York Zoological Society in 1895, the Wildlife Conservation Society is dedicated to ensuring a future for wildlife and wild lands. The Society founded the first field veterinary program in 1989 to examine the connections between people, domestic animals, and wildlife; this paradigm was named "One World, One Health." Currently, humanity is plagued by 1,407 known pathogens, 58 percent of which are zoonotic. Four main driving forces that need to be examined are increases in human population, global climate change, intensified agricultural practice, and globalization and trade. Although the global agricultural trade is well defined, the global wildlife trade is not because much of it is illegal; this trade poses a large health threat to people and other animals. Of particular concern is the trade and introduction of exotic, alien, and non-native or invasive plants and animals. Annually, tens of millions of wild animals are shipped for food, pets, and traditional medicines. In early 2003, more than one-third of the legal global meat trade was embargoed as a result of bovine spongiform encephalopathy, avian influenza, and other livestock disease outbreaks. Each year, 350 million live plants and animals are shipped globally; approximately 40,000 of those are live primates; 4 million live birds; and 640,000 live reptiles; and each of these groups is associated with diseases that have the potential for transfer to humans and other animals. Regarding trade at the local and regional level, wild meat consumption in Central Africa is 1 billion kilograms per year, which is roughly 200 million animals per year. By placing the animals in unsanitary, stressful situations, and with people working in close proximity with those animals, a health risk situation is nurtured. In the case of avian influenza, the poultry share living space with people on the farms and are free to roam about. Wild birds are known to be the reservoir for low-pathogen avian influenza, but not for high-pathogen avian influenza. When the wild birds are mixed with the domestic birds (where sanitation is poor) and animals are stressed, the virus has the opportunity to mutate and efficiently pass to human animal handlers. Part of the challenge of predicting avian influenza is tracking the migratory patterns of the birds. To facilitate this area of study, the Global Avian Influenza Network for Surveillance (GAINS) was formed to train people worldwide to test samples from birds as well as to report the migration of healthy birds. Working with partners, a database is being created to share among scientists and interested parties, and the GAINS Web Site is operational. The goal is to produce models to predict avian influenza movement worldwide. An example of training in the field began in 2005, with instruction to Mongolian scientists on how to sample for avian influenza in the field. This training should create a standard from which to compare changes in the environment over time. To lessen the emergence and reemergence of zoonotic disease, there is a need for wildlife surveillance systems, expanded inspection and quarantine systems, and improved communication between agencies, governments, and NGOs.

Discussion

Dr. Randolph asked about the current view of the relative importance of natural migration of birds and the illegal trade in poultry in terms of spreading agents of disease. This information is not known, Dr. Cook responded, and the current study is working to collect these data. The team has been able to identify birds moving within a region, but whether these wild birds are truly able to carry the disease is not yet known. The team also lacks information on the poultry trade, because it is illegal. He added that there are frequent articles in the newspapers about confiscations of thousands of pounds of illegally traded poultry in the States and in Europe.

VALUATION OF BIODIVERSITY BENEFITS TO HUMAN HEALTH OUTCOMES

Biodiversity Conservation, Climate Change, and Human Health
Subhrendu Pattanayak, RTI International

Work was undertaken to examine climate change, human health, and biodiversity conservation and the valuation of biodiversity in the context of disease regulation in Brazil. The broad questions being addressed include: How does the environment (ecosystem) contribute to human welfare, especially via the human health pathway? What are some of the most significant ecosystem changes where expected environmental health outcomes occur, such as climate change or protected areas? What conceptual approaches and modeling tools can be used to address these types of questions (e.g., spatial, multimethod)? Information from the literature suggests that human health is affected adversely by climate change, and that alteration of the habitat, such as through deforestation, increases malaria risk. Brazil was employed as an ideal laboratory for the study because the country experiences strong variation in several variables, including climate, biodiversity, health, landscape, and education. Brazil also has some of the highest levels of deforestation in the world, is vulnerable to climatic changes, and has among the best public policy data available over time and space in the tropics. The study analyzed public data on approximately 500 microregions to estimate climate and conservation impacts on morbidity. Studies included estimating econometric models using the cross-sectional variation in morbidity, climate, and conservation data. Models controlled for such variables as demographics, health care access, income, and other regional characteristics. Past work has shown that warmer, wetter climate is positively associated with morbidity and that deforestation is positively correlated with malaria. A computational general equilibrium (CGE) model was used to give a picture of the economic consequences of climate change and morbidity; the model is calibrated for current and projected conditions in Brazil. When no action is taken at baseline, and climate is permitted to affect morbidity and deforestation, the model predicts a reduction in effective labor supply of 0.47 percent. Under one policy scenario accounting for the conservation of 50 million hectares of forests by 2010, morbidity impacts are reduced to 0.39 percent by the elimination of deforestation. Accompanying climate change impacts is a reduction in the gross domestic product, investments, and imports; these three measures increase with forest conservation. Future extension of the work will include disaggregation of labor and conservation by region and a review of all interactions and feedbacks with conservation and climate scenarios, and with climate change mitigation policies. The research has emphasized the need for a multidisciplinary and multimethod approach to address biodiversity, environment, and human health issues.

Discussion

Dr. Achache commented that one result of deforestation in Brazil is the creation of biofuels, the commercialization of which will generate a tremendous amount of wealth once that material is exported. How can this outcome be factored into the model? Dr. Pattanayak responded that with this model, these effects are the net of the loss that Brazil is suffering because it cannot cut a lot of the species to use in agriculture. Thus, the health effects are mediating some of the production effects from taking land away from agriculture. Biofuels may not be in the model, but they are easy to add. This model is made to answer that question. There are tradeoffs, however, and you will lose something to gain something else. The question is, are the gains higher than the losses?

A participant commented that it seems conservation is occurring in the Amazon proper, while biofuel and soybean industries are growing outside the Amazon proper and much biodiversity loss is taking place outside the areas where protected areas are to be created. He stated that he was surprised to learn that much of the economic loss is attributed to taking land out of production for soybeans, and meanwhile, it seems it may be because land that is being taken out of production in the model is not soybean land nor is it biofuel land; it is very wet areas in the Amazon proper. Dr. Pattanayak responded that one future extension was to try to keep track of landfills, the benefit of landfills, and once we disaggregate this, we will begin to see some of the effects being discussed.

Closing Remarks
Gary Foley, EPA/ORD/NCER

Dr. Foley extended his gratitude to Drs. Pongsiri and Roman, and all the organizers of the workshop. This event has provided a venue in which to examine a problem in which many people are interested and it has drawn attention to the fact that complex problems require innovative approaches. Innovation requires people to think collaboratively, to take a multidisciplinary approach, and to try to accomplish things faster. Dr. Foley referred to comments made by Michael Leavitt, who is now the Secretary of Health and Human Services and who was the former Administrator of EPA, to an audience about 18 months ago, that the world needs acceptance of networks. GEO is one such network into which it will be critical to invest. Dr. Leavitt’s parting words reminded the audience that those who get better at collaboration will prosper. What is needed now is to learn to want collaboration. Dr. Foley encouraged the participants to leave their feedback on the comment form or to send e-mail comments to him, or to Drs. Pongsiri or Roman, on ideas to build a network that can help the various disciplines work together and address problems in parallel. He concluded by thanking the participants for attending, and the speakers for their excellent presentations. The meeting was then adjourned.

Abstracts

Biodiversity and the Dilution Effect: The Case of Lyme Disease

Richard S. Ostfeld
Institute of Ecosystem Studies, Millbrook, NY

The public values biodiversity largely for ethical and aesthetic reasons, and the focus of concern is largely devoted to vertebrates. In contrast, scientific research on the importance of biodiversity focuses on ecosystem functions or services and is largely restricted to microbes and plants. This talk will describe a utilitarian function served by vertebrate diversity, namely, the protection of humans against exposure to zoonotic diseases. The focus will be on Lyme disease, a zoonosis in which ticks acquire the bacterial pathogen from vertebrate reservoir hosts and later transmit it to humans. The blacklegged tick vector is a host-generalist, feeding from many different mammal and bird species, but only acquires Lyme bacteria efficiently from a few hosts, mainly white-footed mice and eastern chipmunks. The ticks also appear to suffer low mortality when feeding from these rodents as compared to other mammalian and avian hosts. High host diversity appears to reduce Lyme-disease risk to people via several distinct mechanisms. First, high host diversity presents the tick population with many opportunities to feed from hosts that are highly inefficient at transmitting Lyme bacteria. Second, high-diversity communities appear to regulate the abundance of white-footed mice via predation and competition. Third, high abundance of non-mouse hosts serves to deflect tick meals away from mice, thus reducing tick infestation of mice. By these mechanisms, high diversity appears to reduce both the infection prevalence of ticks and tick density, thereby reducing Lyme-disease risk. These effects of high vertebrate diversity constitute the "dilution effect."

In the northeastern and midwestern United States where Lyme disease is endemic, small forest fragments tend to sustain smaller numbers of species than do larger forested areas. Possibly as a consequence of reduced diversity therein, white-footed mice, and to some extent chipmunks, tend to thrive in small fragments. Because small fragments support high abundance of rodent reservoirs but low overall diversity, these sites pose the highest risk of Lyme disease. This talk will use both empirical and modeling approaches to assess the dilution effect for Lyme disease, ask whether the dilution effect applies broadly to other zoonoses, and examine the mechanism by which it operates.

The Role of Avian Diversity and Community Composition in West Nile Virus Amplification in the Southeastern United States

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Factors accounting for geographic variation in West Nile virus (WNV) prevalence in the United States are poorly understood. Wild birds are the primary reservoir hosts for WNV, but individual species vary considerably in virus competency, thus differences in avian diversity and community composition may help account for variation in virus amplification rates across habitats. Examining associations between passerine (Passeriform) and non-passerine (all other orders) bird diversity and WNV infection prevalence at two spatial scales in Louisiana, we found that non-passerine species richness was significantly negatively correlated with both mosquito infection rates and human disease incidence. By contrast, passerine species richness was not correlated with either human or mosquito infections. Further analyses suggested that the relative abundance of passerine to non-passerines in a habitat was a strong predictor of virus amplification, with mosquito infection rates being significantly higher in habitats with higher passerine to non-passerine ratios. These findings highlight important links between avian diversity and composition and WNV disease risk, and suggest that biodiversity effects on disease may be a general phenomenon applicable to the dynamics of many vector-borne zoonoses.

Disease Emergence in Terrestrial and Marine Environments

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An environmental source of disease was hypothesized as early as the late 19th century by Robert Koch, but not proven because of the inability to isolate *Vibrio cholerae*, the causative agent of cholera, from the environment between epidemics. Much has changed in the past 100 years, but still standard bacteriological procedures for isolation of microorganisms from environmental samples, including water, between epidemics generally were unsuccessful, and now it is common knowledge that less than 1 percent of microorganisms in the environment have been cultured in the laboratory. Dormancy, sporulation, loss of culturability when conditions are unfavorable for growth, and reproduction are conditions of life amongst microorganisms that make it difficult to assess their presence. Furthermore, the association of *V. cholerae* with zooplankton, notably copepods, explains the sporadicity and erraticity of cholera epidemics, which now have been correlated also with climate and climate events, including El Niño. Because zooplankton have been shown to harbor the bacterium and zooplankton blooms follow phytoplankton blooms, remote sensing has been successfully employed to determine the relationship of cholera epidemics with sea surface temperature (SST), sea surface height (SSH), chlorophyll, turbidity, and related environmental factors. Cholera occurs seasonally in Bangladesh, with two annual peaks in the number of cases. From clinical data and data obtained from remote sensing, it has been found that when the height of the ocean is high (SSH) and SST also is elevated, cholera cases are most numerous. SST, SSH, and blooms of plankton have been significantly correlated with cholera epidemics and selected climatological factors and incidence of *V. cholerae* recorded, making possible prediction of cholera epidemics, both their geographical location and intensity. Other disease agents are recognized as having an environmental source (e.g., avian influenza, hantavirus, *Campylobacter*, etc.). Clearly, a holistic approach to infectious diseases, taking into account environmental parameters, is required for public health safety in the 21st century.

Emergence of Tick-Borne Pathogens in the Northeast United States

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A total of seven tick-borne pathogens capable of infecting humans circulate within natural zoonotic cycles in the Northeastern United States. Five of these have emerged within the past four decades. Four tick species vector these seven pathogens, but five of them are vectored by a single tick species, *Ixodes scapularis.* Recent range expansion of *I. scapularis* and *Amblyomma americanum* explains the emergence of most new pathogens, but slow recognition of clinical cases in humans also can contribute to emergence. Range expansions of tick species with overlapping host preferences provide new opportunities for cross species transmission of pathogens among vertebrate hosts and vectors. Predicting disease emergence and developing intervention strategies is a challenge to public health agencies.

Changes in biodiversity greatly impact the risk of tick-borne infections for humans. Increased host diversity may not only reduce the force of transmission for one pathogen, but also it may increase the overall diversity of both tick vectors and transmissible pathogens. Management decisions affecting biodiversity should consider the potential public health consequences, both positive and negative, to avoid potential conflicts. An aggressive and interdisciplinary effort to balance the interests of biological conservation and public health is long overdue.

HSD SGER: The Role of Coastal Ecosystem Degradation in Tsunami Damage

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To what extent did coastal ecosystem degradation increase the vulnerability of coastal communities in the December 2004 Indian Ocean tsunami disaster? To what extent do community-based social capital (features of social organization such as networks and trust that enable collective action) and international aid delivery systems influence village performance in mangrove protection? This exploratory study addresses these questions based on perspectives from the biophysical and social sciences. The initial focus is on the Andaman coast of Thailand.

The biophysical phase of the study uses data from satellite imagery. We conducted remote sensing analysis to identify pre-disaster mangrove change and post-disaster structural damage and landscape changes (see Figure 1). We gathered field data at five sites (20 villages), deploying the *VIEWS*™ data collection system, to validate and supplement this analysis. A major finding was that mangroves are one of many factors that influenced tsunami damage intensity, but they appear to have been an effective buffer against tsunami forces. Villages that were behind substantial mangrove forests suffered relatively little damage, while otherwise comparable villages that were not so protected were devastated.

The social science phase entailed an evaluation of 6 of the 20 villages. During August 2005, semi-structured interviews were conducted with 18 local leaders who were knowledgeable and influential about mangrove ecosystem management and disaster recovery in their villages. Field observations also were undertaken to verify tsunami impacts and mangrove protection practices. An interview protocol was derived from the World Bank's *Social Capital Assessment Tool* to: (1) gauge village performance in mangrove protection; (2) determine the level of social capital in the village; and (3) assess the role of external aid delivery organizations.

A major finding was that social capital was not consistently related to the extent to which villages undertook mangrove conservation practices. Although social capital was clearly high or moderately high in all 6 villages, there was considerable variation in the level of conservation practices. In villages with high levels of social capital, performance in conservation drops when external organizations deny grassroots-level networks to respond to local conservation needs. In contrast, the highest performing village in conservation efforts had strong social capital that was activated when external organizations took a bottom-up approach in dealing with local people. The combination of strong internal bonding and strong linkages with external organizations during the recovery period led to considerable improvement in mangrove conservation practices. Policy and research implications of these findings are discussed.

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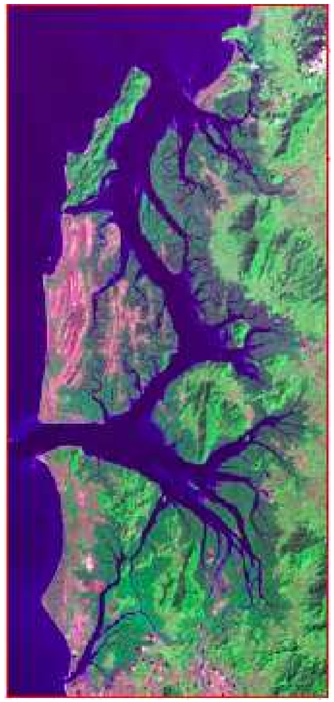

Figure 1. Example of mangrove area from Landsat imagery.

Soils, Biodiversity, and Links to Human Health

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The inclusion of soil organisms (both microbes and fauna) as causal agents of human disease is generally considered as being limited to tropical or less developed countries, but it is a global issue. Information on the triggers, biotic and/or abiotic that drive the incidence of soil organism-related disease is fragmented and disciplinary. The pathology of the soil organism in causing disease is often studied in isolation and rarely related to its natural history, soil habitat, or ecology. Soil biodiversity in less disturbed systems is determined by multiple factors over evolutionary time, such as vegetation (chemical quality, quantity, plant species, and community composition), soil physical and chemical properties, and climate. Environmental factors leading to higher incidence of soil-borne organisms and human disease, such as disturbance to soil, climate change, increasing human population, poverty, and the resulting impact on soil food webs should be integrated to better predict disease occurrence. Disturbances to soil impact ecosystem functioning, soil physical and chemical factors, alter soil biodiversity, and appear to be associated with the loss of ecosystem services such as control of pathogen-predator outbreaks. Understanding the relationships between soil, biodiversity, and links to human disease is a new interdisciplinary challenge that is central to an ecosystem approach to human health.

Biodiversity Loss and the Ecology of Infectious Disease Transmission Among People, Primates, and Domestic Animals in Kibale National Park, Uganda

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Infectious diseases transmitted among humans, non-human primates, and domestic animals represent an emerging threat to human health, animal health, and primate conservation. The Kibale EcoHealth Project endeavors to improve our understanding of how biodiversity reductions alter interspecific infectious disease transmission risks in and near Kibale National Park, a mid-elevation forested park near the foothills of the Rwenzori Mountains in western Uganda. Project data indicate that forest fragmentation has led to 75 percent reductions in non-human primate biodiversity. These dramatic reductions in primate biodiversity have led to the competitive release of some species, resulting in changes in primate density and behavior; these changes in turn have led to increased prevalence of a broad variety of directly transmitted and water-borne pathogens in non-human primates inhabiting forest fragments (e.g., strongyle and rhabditoid nematodes, protozoa of the genera *Giardia* and *Cryptosporidium*, and various species of pathogenic enterobacteria). Epidemiological surveys of domestic animals living near forest fragments implicate cattle, goats, and sheep as reservoirs and conduits of infection between people and primates. Molecular analyses of bacteria isolated from humans living near forest boundaries or employed in primate-directed eco-tourism indicate that specific human behaviors that increase ecological overlap between people and primates also accelerate microbial transmission rates. Patterns of antibiotic resistance in these same bacteria show that human-livestock-primate microbial transmission risk is spatially structured, with forest fragmentation being a key factor accelerating transmission. Spatially explicit analyses suggest that the link between biodiversity loss and human-primate disease transmission is mediated by human behavior, primate behavior, and hydrology. A working model of this process is that: (1) human behavior (driven by socioeconomic and cultural factors) causes forest fragmentation and plant biodiversity declines; (2) non-human primate biodiversity declines rapidly in response to these changes, and the remaining primates experience dramatic demographic and behavioral changes; (3) alterations in primate demography and behavior "force" primates into atypical ecological interactions, including interactions with humans and livestock; (4) these atypical ecological interactions lead to increased disease transmission risk; and (5) these processes are most pronounced in low-lying forest fragments, where primate population densities are high, human encroachment rates are high, and hydrological processes create physical reservoirs for environmentally persistent pathogens. A fine-scale understanding of the mechanisms by which anthropogenically driven biodiversity declines alter interspecific infectious disease transmission risks between people and non-human primates will be essential for the formation of improved conservation and public health strategies that would benefit human health on both a local and global scale.

Deforestation and Anopheline Biting Patterns in Amazonian Peru

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Iquitos in Amazonian Peru has undergone substantial human settlement and expansion during the past decade. Despite a long history, the city remains fairly isolated from much of the rest of the region and historical entomological surveys make this an excellent site to examine the impact of human development on vector-borne diseases, such as malaria. During 2000-2001, collaborators undertook studies to examine the relationship between the abundance of *Anopheles darlingi*, a major vector of human malaria in South America, and deforestation that accompanied human activity. This discussion focuses on the relationship between deforestation and human landing rates. *A. darlingi* was much more common in deforested areas than in regions that remained relatively undisturbed, even when accounting for the presence of humans. This is interpreted to represent a significant increase in human disease risk for malaria transmission. This study provides a good example of both the strengths and challenges of establishing the relationship between human activities, biodiversity, and public health.

International Perspective: Research on Environmental Change and Emerging Human Diseases

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In recent years, several vector-borne, parasitic or zoonotic diseases have (re)-emerged and spread in different parts of the world, with major health, ecological, socio-economical, and political consequences. Most of these outbreaks are linked to global and local changes resulting from climate change, human-induced landscape changes, or the activities of human populations that affect the ecology of the diseases and risk of infection.

EDEN (Emerging Diseases in a changing European eNvironment, www.eden-fp6project.net) is an ongoing integrated project of the European commission that aims to identify, evaluate, and catalogue European ecosystems and environmental conditions linked to global change, which can influence the spatial and temporal distribution and dynamics of human pathogenic agents. The final project objective is to develop methods, tools, and skills such as predictive models of emergence and spread, and novel approaches for early warning, surveillance, and monitoring. These can be used by decision makers for risk assessment, and decision support for intervention and public health policies. The project integrates research in 47 leading institutes from 24 countries, and the eco-geographical diversity of the project area covers all relevant European eco-systems from the polar circle in the north to the Mediterranean basin and its link with West Africa in the south, and from Portugal in the west to the Danube delta in the east.

EDEN is organized into a series of vertical sub-projects focused on “indicator diseases”, linked together by a series of integrative activities that include environmental change detection, disease modelling, and biodiversity monitoring. More specifically, this last field explores the interactions between pathogens, vectors, hosts, and their environment in terms of interfaces in time and space, co-adaptation and selection, population and community dynamics. Example of ongoing activities relevant to the current discussion of the impact of biodiversity on human health will be selected from the tick-borne diseases (TBD) and West Nile (WN) subprojects.

Within the TBD project, data are being collated on the impact of environmental changes or human intervention on the availability of wildlife and livestock hosts; these include a range of large wildlife species and livestock as hosts for (adult) ticks, and rodents as transmission hosts for tick-borne encephalitis virus and Lyme borreliosis spirochetes. Given the paucity of historical data on tick populations, new intensive fieldwork at four to six sites in each of 11 countries over 3 years will allow us to relate the spatially variable abundance and/or seasonal dynamics of local tick populations, and the prevalence of their infection with tick-borne pathogens, to current host diversity and abundance.

Within the WN project, contrasting disease patterns are explored, from endemic foci in Africa to sporadic incursions in European wild avifauna areas or urban transmission in Bucharest. Wild birds are involved in the transmission and the spread of WNV, but diversity in vectors and virus populations also are key elements of the natural history of the disease in Europe. Effects of area-specific community dynamics, invasion pathways, and biodiversity sanctuaries (notably in river deltas) are assessed.

Mother Nature's Pharmacopoeia

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For millennia, humans (and animals) have utilized plants as sources of medications, simply proceeding on the basis of what worked to alleviate "pain and suffering". With the identification in the early 1820s of morphine from the opium poppy, the following two centuries have seen the isolation and identification of large numbers of active agents from all sources, a significant number of which have become and still are, medicinal agents used world-wide. About 25 years ago, the use of natural product materials as leads to novel agents in industry went into decline, but these are now beginning to come back into play as a source of "chemical skeletons", due in part to the lack of success of its replacement, combinatorial chemistry as a lead generator. Couple to this, the realization from genetic analyses, that what was originally thought to be the source organism, may actually be a single-celled organism in a large number of cases, then the paradigm should shift from "conservation of the host organism (e.g., a tree/plant)" to "we need to identify the microbe(s) involved and their host environment". As a result, one can now say that the most diverse "set" of organisms on the planet are those that we cannot see, and guesstimates of the number of species are well above 10^{30}. Thus, the loss of hosts is only the part that one can see, the true losses are significantly larger. Examples of important materials and the possibilities for the future involving microbial sources (and their hosts) will be presented.

The Plants and People Project of Micronesia: Perspectives in Understanding the Relationship of Integrative Medicine, Traditional Knowledge, and Biodiversity

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Integrative medicine represents an approach that incorporates the best practices of conventional care and traditional knowledge with a special emphasis on disease prevention and the innate capacity of the body to heal. The evolution of this new form of medicine is catalyzed by the realization of many medical educators and practitioners that other methods of treatment used in traditional cultures can benefit patients, especially those with chronic diseases. Does this new form of medicine add to cultural preservation or further devolution of ancient medical practices by subsuming the old within the new? What is the role of ethnobotany, ethnomedicine, and biodiversity? How can medicine support traditional healers as more modern skills sets are offered? Is there a relationship in ethnobotany and biodiversity to health? What are the applications in underserved developing areas of the world? These questions will be discussed in relationship to the Plants and People Project in Micronesia, a multidisciplinary ethnobotanical, medical, and ecology project begun in 1998 under the direction of Michael Balick, Ph.D., from The New York Botanical Garden, and Roberta Lee, M.D., Medical Director of the Center for Health and Healing at Beth Israel Medical Center in New York. The project focus has been to establish a botanical checklist, begin an initiative to record traditional/cultural use of plants for medicine, housing, and other uses as well as record specific information on traditional medicine beliefs. The specific area of study has focused on Pohnpei, an island in the Eastern Caroline Islands that is known as one of the islands in the Federated States of Micronesia. These islands are considered one of the biodiversity "hot spots" in the world—an area with a high concentration of endemic plants that are at risk of habitat loss. The project now in its eighth year is expanding to other islands within the Federated States of Micronesia. The project has included contributions from more than 100 Micronesian participants. The participants have included acknowledged traditional medicine elders and Micronesian conservationists and each has provided invaluable ethnobotanical editorial assistance during this project. This co-operative effort will produce a compilation of its ethnobotanical findings in a text due out for publication in the spring of 2008. In addition, a primary health manual on traditional Micronesian plant use on Pohnpei is under development.

Applications to the Global Earth Observation System of Systems

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The intergovernmental Group on Earth Observations (GEO) is leading a worldwide effort to build a Global Earth Observation System of Systems (GEOSS) over the next 10 years. The GEOSS will work with and build upon existing national, regional, and international systems to provide comprehensive, coordinated Earth observations from thousands of instruments worldwide, transforming the data they collect into vital information for society. The mission of the GEO will be outlined and the role of the GEOSS in delivering societal benefits in nine target areas will be described. In particular, the benefit of understanding environmental factors affecting human health will be highlighted, focusing on the links between biodiversity, ecosystem services, and health.

The Trade in Wild Animals: A Threat to the Health of People, Domestic Animals, and Wildlife

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Increasingly diseases are moving between people, domestic animals, and wildlife, creating concerns about food safety, public health, and wildlife conservation.[1] Some of these diseases have been with us for millennia, while others are emerging or re-emerging, gaining the ability to jump between species and overloading our traditional methods of disease surveillance and prevention. In a list of 1,407 human pathogens, 58 percent are known to be zoonotic. There are 177 that are categorized as emerging or reemerging, and zoonotic pathogens are twice as likely to be in this category versus nonzoonotic pathogens.[2]

The local hunting of wildlife or bushmeat is an ancient practice that forms the fabric of community culture at the rural wildlife interface. Although these fundamental practices have always posed a cross-species disease risk to the local community, they have been mitigated through cultural practices. Ecological change such as those brought on by increases in human population density, forest fragmentation via road building and rural development alter the relationships of pathogens to hosts.[3] This coupled with increased human movement and the globalized trade in animals for food and pets facilitate rapid movement to distant sites and greater human-pathogen contact.[4] The World Trade Organization's 2005 statistics note that in 2004 the global merchandise trade rose by 21 percent to $8.9 trillion U.S. dollars, with agriculture accounting for $783 billion U.S. dollars. There is no breakdown of the share of trade in wildlife, but each year roughly 350 million live plants and wild animals are shipped globally.[5] The poorly regulated wildlife component of global trade facilitates infections via microbial travel at scales that not only cause human disease outbreaks but also threaten livestock, international trade, rural livelihoods, native wildlife populations, and the health of ecosystems.[6,7,8]

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Valuation of Biodiversity Benefits to Human Health Outcomes

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Part of the puzzle surrounding biodiversity loss lies in an incomplete understanding of how humans value the functions and services that flow from biodiversity conservation. Unfortunately, there is a lot of smoke and mirrors surrounding the links between biodiversity conservation, climate change, human health, and social welfare. This paper revisits some aspects of ecosystem valuation—purpose, methodology, and policy design and implementation by looking closely at the links between climate change, human health, and biodiversity conservation. We use publicly available data on Brazilian micro-regions to present a concrete empirical example of ecosystem valuation in the form of disease regulation by biodiversity conservation, against a backdrop of climate change. There is a small but growing literature that suggests that human health in tropical regions will be: (a) adversely impacted by climate change, and (b) biodiversity conservation will mediate this impact. For example, the establishment of parks and protected areas for preventing deforestation and associated land uses can reduce illnesses such as malaria, which have significant ecological risk factors. We employ econometric models of secondary data from Brazil to test these hypotheses and estimate parameters that link climate change and biodiversity conservation to malaria cases. We then apply a dynamic computable general equilibrium (CGE) model to provide a comprehensive picture of the economic consequences of biodiversity and climate change. Although the most significant direct impact of malaria is on the labor force, such labor market impacts are often the catalyst for economy-wide effects because of spillovers onto other markets and sectors. In addition, climate change is a complex phenomena that will play out in the medium to long term and over a broad spatial landscape. Across such a time and space dimension, we also can expect to see other ecologically significant policies such as large-scale conservation in Brazil. Thus, we feed the econometric parameters into a dynamic CGE, calibrated for current and projected conditions in Brazil, to measure impacts on gross domestic product, labor force, agricultural yields, commodity prices and wages, and forest cover. The methodology applied in this paper represents a rare example of how statistical estimation using secondary survey and administrative data can be combined with CGE models to evaluate climate change and conservation scenarios for policy design. Finally, we offer two conclusions. First, conservation policymakers should consider outcomes of habitat conservation that lie outside the traditional conservation paradigm by considering species saved and landscapes protected to be intermediate outputs in the improvement of human welfare. It should always be possible to monetize, quantify, or at the very least identify these welfare impacts. Second, it is imperative that multidisciplinary teams conduct conservation "policy experiments" to identify causal outcomes (including defensible estimates of ecosystem values) to improve the design and evaluation of biodiversity conservation policies. As indicated by this study, we join the growing chorus of sustainability scientists, eco-epidemiologists, socioecological systems modelers, and biocomplexity researchers in calling for transdisciplinary research that recognizes the interrelationships among ecology, human behavior, economics, epidemiology, and physical processes.

Biographical Sketches

Biographical Sketches

José Achache is the Director of the Secretariat of the Group on Earth Observations (GEO). The Secretariat serves as the center of international coordination for the Global Earth Observation System of Systems (GEOSS). As Director of the Secretariat, Dr. Achache is responsible for managing the programmatic and administrative support to GEO, coordinating the development and implementation of GEOSS activities, and maintaining effective working relationships with the broader GEO community.

Of French nationality, he graduated from the Ecole Normale Superieure in Paris. He obtained his doctorate in Geophysics at the Pierre et Marie Curie University in 1979 and his doctorate in Physical Sciences at the René Descartes University. He was a Visiting Scholar at Stanford University from 1979 to 1980.

He began his career at the Institut de Physique du Globe de Paris as a Research assistant, then “Chargé de Recherche,” and in 1989 was appointed Professor, Director of the Department of Space Studies and Director of the Graduate School of Earth Sciences. In 1996, he joined the French Geological Survey (BRGM) as Deputy Director of the Research Division and the following year became its director. In 1999, he was named advisor to the President of the French Space Agency (CNES) and in 2000, was appointed to the post of Deputy Director General for Science. In 2002, he was appointed Director of Earth Observation for the European Space Agency (ESA). While at ESA, he initiated the GMES programme in partnership with the European Commission.

Philip R. Berke is Professor of Land Use and Environmental Planning, Department of City and Regional Planning at the University of North Carolina-Chapel Hill, and Director of the Center for Sustainable Community Design of the Carolina Environmental Program. His research focuses on the connections between the dynamics of urban development, how development impacts natural environmental systems, and the consequences of these impacts on human settlements. He recently served as a member of the Committee on Disaster Research in the Social Sciences of the National Research Council, National Academies (2004–2006). Dr. Berke’s current research focuses on how well alternative urban forms integrate risk mitigation practices in floodplain ecosystems, and capacity-building in disadvantaged communities that are highly vulnerable to natural disasters. He received his Ph.D. degree in Urban and Regional Science from Texas A&M University.

Rita Colwell is a Distinguished University Professor both at the University of Maryland at College Park and at Johns Hopkins University Bloomberg School of Public Health and Chairman of Canon US Life Sciences, Inc. Her interests are focused on global infectious diseases, water, and health, and she is currently developing an international network to address emerging infectious diseases and water issues, including safe drinking water for both the developed and developing world.

Dr. Colwell served as the 11th Director of the National Science Foundation (NSF), 1998–2004. In her capacity as NSF Director, she served as Co-Chair of the Committee on Science of the National Science and Technology Council. One of her major interests include K-12 science and mathematics education, graduate science and engineering education, and the increased participation of women and minorities in science and engineering.

Dr. Colwell has held many advisory positions in the U.S. Government, nonprofit science policy organizations, and private foundations, as well as in the international scientific research community. She is a nationally respected scientist and educator, and has authored or co-authored 16 books and more than 700 scientific publications. She produced the award-winning film, “Invisible Seas,” and has served on editorial boards of numerous scientific journals. Before going to NSF, Dr. Colwell was President of the University of Maryland Biotechnology Institute and Professor of Microbiology and Biotechnology at the University Maryland. She also was a member of the National Science Board from 1984 to 1990.

Dr. Colwell has previously served as Chairman of the Board of Governors of the American Academy of Microbiology and also as President of the American Association for the Advancement of Science, Washington Academy of Sciences, American Society for Microbiology, Sigma Xi National Science Honorary Society, and the International Union of Microbiological Societies. Dr. Colwell is a member of the National Academy of Sciences; Royal Swedish Academy of Sciences, Stockholm; Royal Society of Canada; American Academy of Arts and Sciences; and the American Philosophical Society.

Dr. Colwell also has been awarded 47 honorary degrees from institutions of higher education, including her Alma Mater, Purdue University, and is the recipient of the Order of the Rising Sun, Gold and Silver Star, bestowed by the Emperor of Japan. She is an honorary member of the microbiological societies of the United Kingdom, Australia, France, Israel, Bangladesh, and the United States, and has held several honorary professorships, including the University of Queensland, Australia. A geological site in Antarctica, Colwell Massif, has been named in recognition of her work in the polar regions.

Born in Beverly, Massachusetts, Dr. Colwell holds a B.S. degree in Bacteriology and an M.S. degree in Genetics from Purdue University, and a Ph.D. degree in Oceanography from the University of Washington.

Robert A. Cook is the Chief Veterinarian and Vice President of the Wildlife Health Sciences (WHS) Division of the Wildlife Conservation Society (WCS) and an Adjunct Assistant Professor at Columbia University in New York City. He has more than 20 years of experience in zoo and wildlife medicine and has served in his present capacity as Chief Veterinarian for the last 13+ years. It was under Dr. Cook's guidance that the Field Veterinary Program was established in 1989 as the first global effort to support the health and conservation of wildlife populations in native habitats. The Field Veterinary Program recently has begun implementation of a multi-agency, multi-sectoral, and world-wide initiative, the wild bird Global Avian Influenza Network for Surveillance (GAINS). The WHS programs in Clinical Care and Pathology are responsible for the health of more than 20,000 animals in five New York facilities, including the Wildlife Centers in Central Park, Queens and Prospect Park, the New York Aquarium, and the Bronx Zoo. With the Field Veterinary Program taking the lead, WHS is deeply involved in the health aspects of the Wildlife Conservation Society's international conservation programs, providing services and research to a number of the 400 WCS projects in 60 nations.

Dr. Cook graduated from the University of Pennsylvania School of Veterinary Medicine in 1980 and pursued a career in zoo and wildlife medicine thereafter. Recently, he fulfilled his desire to have a more global impact on wildlife health issues by returning to school to receive his Master in Public Administration from Columbia University in 2002. With his background in both the health of wildlife and global policy issues on these matters, he accepted an adjunct teaching position at Columbia University in its School of International and Public Affairs.

Dr. Cook is currently Chair of the Captive Wildlife and Alternative Livestock Committee of the United States Animal Health Association. He is a past President of the American Association of Zoo Veterinarians. Dr. Cook also has a long-standing interest in pain amelioration and is a scientific advisor to the Mayday Fund. In addition, he served as a scientific advisor to the Morris Animal Foundation and as a member of the Conservation Endowment Fund Committee of the AZA. He has been author or co-author of more than 100 scholarly publications in scientific journals, proceedings, and books.

Stéphane de La Rocque graduated from the veterinary school of Lyon (France) in 1991. He has more than15 years of experience in the field of vector ecology, spatial epidemiology, and remote sensing. He started his career in South America on the epidemiology of hemoparasites of cattle in French Guyana, Surinam, and Guyana. Then he spent 7 years in Bobo Dioulasso (Burkina Faso) working on tsetse flies and their control. He was actively involved in the management of bluetongue and West Nile outbreaks in Southern France and was leading a Cirad research team on arboviroses (West Nile and Rift Valley Fever) in Dakar (Senegal). In 2004, he left Senegal to coordinate a new project of the EC on environmental changes and emerging diseases in Europe. He is now based in the Emergency and Prevention System Program of the Food and Agriculture Organisation of the United Nations in Rome, Italy.

Vanessa Ezenwa received her Ph.D. degree from Princeton University in 2002 (Host Behavior and Parasitism Risk in Ungulates). She had a National Research Council Postdoctoral Fellowship, 2003–2005, USGS National Science Center, Reston, VA (Ecology of WNV in Southeastern Louisiana). Dr. Ezenwa is an Assistant Professor in the Division of Biological Sciences at the University of Montana, Missoula, MT, from 2005 to present. Her current research focuses on: (1) effects of landscape change on avian community composition and physiological resilience and consequences for WNV transmission; (2) interactions between macro- and microparasites and effects on host and parasite dynamics; and (3) ecology of multi-host parasites in ungulate communities.

William H. Farland is currently the Acting Deputy Assistant Administrator for Science in the U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD). In 2003, Dr. Farland also was appointed Chief Scientist in the Office of the Agency Science Advisor. He served as Acting Science Advisor throughout 2005. Formerly, he was the Director of the ORD's National Center for Environmental Assessment (NCEA), which has major responsibility for the conduct of chemical-specific risk assessments in support of EPA regulatory programs, the development of Agency-wide guidance on risk assessment, and the conduct of research to improve risk assessment. Dr. Farland's 27-year federal career has been characterized by a commitment to the development of national and international approaches to the testing and assessment of the fate and effects of environmental agents. Dr. Farland holds a Ph.D. degree (1976) from the University of California-Los Angeles in Cell Biology and Biochemistry. He serves on a number of executive-level committees and advisory boards within the Federal government. He currently Chairs the Executive Committee of the National Toxicology Program (NTP). He also is a member of the Scientific Advisory Council of the Risk Sciences and Public Policy Institute, Johns Hopkins University School of Hygiene and Public Health, a public member of the American Chemistry Council's Strategic Science Team for its Long Term Research Program and Member of the Programme Advisory Committee for the World Health Organization's International Programme on Chemical Safety. In 2002, Dr. Farland was recognized by the Society for Risk Analysis with the "Outstanding Risk Practitioner Award," and in 2005 was appointed as a Fellow of the Society. He continues to teach and publish and has been a member of the Editorial Board for *Risk Analysis*, *Environmental Health Perspectives*, and *Chemosphere*.

Durland Fish is a Professor of Epidemiology at Yale School of Medicine. Dr. Fish, a native of Berwick, Pennsylvania, received his B.S. degree at Albright College in Reading, Pennsylvania, in 1966 with a major in Biology and a minor in Chemistry. Upon graduation, he was employed with the Pennsylvania Department of Health as a sanitarian and in 1967 became Regional Vector Control Coordinator in charge of insect and rodent-borne diseases. His investigation of a fatal case of Rocky Mountain spotted fever in 1968 stimulated a career in public health entomology. In 1970, Dr. Fish entered the graduate program in entomology at the University of Massachusetts in Amherst where he received his M.S. degree in 1973. He went on to continue his graduate studies at the University of Florida, where he received his Ph.D. degree in Entomology with a minor in Ecology in 1976.

Dr. Fish studied vector ecology at the University of Notre Dame with a fellowship from the National Institutes of Health. He went to New York in 1980 as an Assistant Professor of Biology at Fordham University, where he taught ecology and medical entomology. In 1985, he joined the faculty at New York Medical College, where he was Associate Professor in the Department of Community and Preventative Medicine and Director of the Medical Entomology Laboratory, and became Director of the Lyme Disease Research Center in 1990. He is now Professor of Epidemiology in the Department of Epidemiology and Public Health at Yale School of Medicine, Director of the CDC Fellowship Training Program in Vector-Borne Disease, Director of the Yale Institute of Biospheric Studies Center for EcoEpidemiology, and Vice Director of the Graduate Program in Integrative Biology. His research on epidemiology and prevention of vector-borne disease has been supported by the National Institutes of Health, Centers for Disease Control and Prevention, U.S. Department of Agriculture, National Aeronautics and Space Administration, Sandia National Laboratory, New York State Department of Health, Wildlife Conservation Society, Mathers Charitable Foundation, and the American Lyme Disease Foundation. He has been awarded the honorary degrees of Doctor of Science from Albright College and Master of Arts from Yale University.

Dr. Fish is a member of many professional scientific societies, including the American Association for the Advancement of Science, the Entomological Society of America, and the Ecological Society of America. He has served as Chairman of the Medical and Veterinary Entomology Section of the Entomological Society of America, President of the New York Entomological Society, and President of the International Northwestern Conference on Diseases in Nature Communicable to Man. He also served on Executive Boards for the Society for Vector Ecology, Acarological Society of America, and the American Committee on Medical Entomology of the American Society of Tropical Medicine and Hygiene. He has served on Editorial Boards for *Emerging Infectious Diseases* and the *Journal of Medical Entomology*, and is Founding Editor of *Vector-Borne and Zoonotic Diseases*. He has presented more than 100 papers at professional meetings and has published more than 130 scientific journal articles in entomology, ecology, and medicine. His work has been featured in *Time* magazine, *Newsweek*, *Science*, *Science News*, *Audubon* magazine and *The New York Times*, and he has appeared on numerous television programs, including NBC News, NBC Today Show, ABC Nightline, CBS This Morning, and was featured in documentaries produced by The Discovery Channel and BBC.

Gregory Glass received his Ph.D. degree in Ecology, with an emphasis in Population Biology from the University of Kansas in 1983. His dissertation developed theoretical models of the evolution of behavior with frequency-dependent selection. He completed his postdoctoral training in Immunology and Infectious Diseases at the Johns Hopkins School of Public Health from 1984 to 1986, where he was involved in the first detailed characterization of hantavirus transmission biology among wild rodents and its public health consequences for the urban human population. He joined the faculty in Molecular Microbiology and Immunology and was promoted to Professor in 2002. His research involves vector-borne and zoonotic agents affecting humans and emphasizes factors influencing the maintenance and transmission of these agents. For the past 15 years, much of his work has focused on methods and approaches to identify leading environmental indicators of disease risk.

Tony L. Goldberg received his B.A. degree from Amherst College and his Ph.D. degree from Harvard University in Biological Anthropology (genetics, biogeography, and conservation of chimpanzees). He received his D.V.M. degree and M.S. degree in Epidemiology from the University of Illinois (molecular epidemiology of viral pathogens). He is an Associate Professor of Epidemiology at the University of Illinois in Urbana-Champaign in the Pathobiology Department. His other affiliations include: (1) University of Illinois Program in Ecology and Evolutionary Biology; (2) Illinois Natural History Survey; (3) University of Illinois Department of Anthropology; and (4) Director of the new University of Illinois "Earth and Society Initiative in Emerging Infectious Disease and Ecosystem Health." His research interests include ecology, epidemiology, and evolution of infectious disease, with a special focus on zoonoses, emerging infections, and diseases at the interface of wildlife conservation and human health.

Conrad C. Lautenbacher, Retired Navy Vice Admiral, has served as the Under Secretary of Commerce for Oceans and Atmosphere and Administrator of the National Oceanic and Atmospheric Administration (NOAA) since December 19, 2001. A graduate of the U.S. Naval Academy, he holds M.S. and Ph.D. degrees in Applied Mathematics from Harvard University. His Navy experience includes duties as Commander of U.S. Naval Forces Central Command Riyadh during Operations Desert Shield and Desert Storm, where he was in charge of Navy planning and participation in the air campaign. A leader in the introduction of cutting-edge information technology, he pioneered the use of information technology to mount large-scale operations using sea-based command and control.

As NOAA administrator, he spearheaded the first-ever Earth Observation Summit, which hosted ministerial-level representation from several dozen of the world's nations in Washington, DC, in July 2003. Through subsequent international summits and working groups, he worked to encourage world scientific and policy leaders to advance toward the shared goal of building a sustained Global Earth Observation System of Systems (GEOSS) that will collect and disseminate data, information and models to stakeholders and decision-makers for the benefit of all nations and the world community. The effort culminated in an agreement for a 10-year GEOSS implementation plan. Sixty-five nations, the European Commission, and 43 international organizations now support this effort.

Roberta Lee is Medical Director of the Center for Health, Healing Director of Continuing Medical Education, and Co-Director of the Fellowship in Integrative Medicine at Beth Israel's Continuum Center for Health and Healing (CCHH). She is a board-certified internist and is one of the four graduates in the first class from the Program in Integrative Medicine at the University of Arizona. She is the Membership Chair of the Consortium for Academic Health Centers for Integrative Medicine. She also is a contributing editor of *EXPLORE: The Journal of Science and Healing* and on the Editorial Board of *HerbalGram*, an evidence-based botanical journal issued by the American Botanical Council. She is the co-editor of the recently released medical text, *Integrative Medicine: Principles for Practice.*

David J. Newman has a D.Phil. degree and works in the Natural Products Branch, DTP, in Frederick, MD. Originally trained as a synthetic chemist, he moved into microbial chemistry for a doctorate and then spent the next 40 years "persuading microbes" (and their hosts) from marine and terrestrial sources to produce agents that could lead to novel treatments for cancer and infectious diseases. Currently, he is the Acting Chief of the Natural Products Branch of the National Cancer Institute (NCI) at NCI-Frederick.

Richard S. Ostfeld received his B.A. degree from the University of California at Santa Cruz in 1979 and his Ph.D. degree from the University of California at Berkeley in 1985. Following a postdoctoral fellowship at Boston University (1985–89), he joined the scientific staff at the Institute of Ecosystem Studies in Millbrook, New York, where he is currently Senior Scientist. He also is Adjunct Professor at Rutgers University and the University of Connecticut. Dr. Ostfeld's research interests involve many aspects of community ecology, particularly those involving interactions between pathogens, vertebrate hosts, vectors, and the surrounding landscapes. He has published more than 120 papers in peer-reviewed journals, written a number of popular articles, and co-edited four books. His research has been covered by the Associated Press, the Discovery Channel, *Time* magazine, the BBC, Radio Free Europe, *Parents* magazine, National Public Radio, *The New York Times*, the *Wall Street Journal*, Reuters, *Science News*, and *Backpacker* magazine, among many others. His work on ecological interactions affecting infectious disease risk is currently supported by grants from the National Institutes of Health and NSF.

Subhrendu K. Pattanayak is a Fellow and Senior Economist for Environment, Health, and Development. He builds microeconometric models to analyze the policy causes and consequences of interactions between human behaviors and environmental services in Brazil, Costa Rica, India, Indonesia, Madagascar, Mexico, Nepal, the Philippines, Sri Lanka, and the United States. Dr. Pattanayak has directed several research projects funded by the World Bank, EPA, the U.S. Department of Agriculture (USDA) Forest Service, Conservation International, Health Canada, and NSF, among others. His research lies in three domains: (a) practical methods for non-market valuation, (b) evaluation of forest ecosystem services, and (c) economics of environmental epidemiology. Most of this research has relied on specifying a testable hypothesis by applying economic theory to environment and development policies, conducting field experiments through household surveys in developing countries, matching the survey (microeconomic) data with meso-scale environmental and social statistics, and estimating econometric models to generate policy parameters and recommendations. Dr. Pattanayak has designed and managed large multi-site household surveys in urban and rural areas of India, Indonesia, Mexico, Nepal, and Sri Lanka. He has published in journals such as *Economics Letters*, *Land Economics*, *American Journal of Agricultural Economics*, *PLOS Biology*, *Environment and Development Economics*, *Agriculture Economics*, *Environment and Resource Economics*, *Forest Science*, *Journal of Forest Economics*, *Forest Policy and Economics*, *Water Policy*, and *Water Resources Research* and presented his research at several international conferences, including the World Congress of Environmental and Resource Economists, American Economics Association meetings, and the National Bureau of Economics Research summer institute. He is a member of the American Economic Association and the Association of Environmental and Resource Economists. Dr. Pattanayak is a Research Associate Professor at North Carolina State University, a Fellow in the Center for Applied Biodiversity Sciences, and a Research Advisor for the South Asian Network for Development and Environmental Economists (SANDEE).

Diana H. Wall, a soil ecologist and environmental scientist, is Professor and Director of the Natural Resource Ecology Laboratory, an international ecosystem research center at Colorado State University. She is actively engaged in research and education. Her research explores how soil invertebrate diversity contributes to human well-being and sustainability of soils, and the consequences of human activities on soil globally. Her research includes 15 seasons in the Antarctic Dry Valleys examining how soil food webs and ecosystem processes respond to global changes and a new global study exploring linkages of aboveground hotspots of biodiversity to those belowground. She chaired the SCOPE Committee on Soil and Sediment Biodiversity and Ecosystem Functioning and is editor of "Sustaining Biodiversity and Ecosystem Services in Soils and Sediments (Island Press, 2004). She chaired the DIVERSITAS-International Biodiversity Observation Year-2001-2002; co-chaired the Millennium Development Goals Committee of the Millennium Ecosystem Assessment; and is Chair, the Global Litter Decomposition Experiment. Dr. Wall served as President of the Ecological Society of America; American Institute of Biological Sciences; Association of Ecosystem Research Centers; the Society of Nematologists; and Chair, Council of Scientific Society Presidents. She received B.A. and Ph.D. degrees at the University of Kentucky, Lexington, and holds an Honorary Doctorate from the Utrecht University in the Netherlands. She is an AAAS Fellow, Society of Nematologists Fellow, and Senior Advisor and Fellow of the Aldo Leopold Leadership Program.

September 15, 2006

Biodiversity and Human Health: A Multidisciplinary Approach To Examining the Links

Smithsonian Institution
S. Dillon Ripley Center
1100 Jefferson Drive, SW
Washington, DC 20004

September 15, 2006

Background

The National Center for Environmental Research (NCER) at the U.S. Environmental Protection Agency's (EPA) Office of Research and Development has proposed a joint Ecosystem-Health research program to study the links between changes in biodiversity and risks to human health. NCER has a responsibility to undertake exploratory research on emerging scientific issues, and workshops are organized for these topical discussions. Studying the relationship between biodiversity and human health is a timely research opportunity. The loss of biodiversity is accelerating while infectious diseases appear to be emerging and reemerging at a faster rate. Research on the links between these two conditions can have an important impact on our view of biodiversity, the services provided by natural ecosystems, and how we manage them.

In co-sponsorship with Yale University's Center for EcoEpidemiology, the Smithsonian Institution, and the World Conservation Union, EPA/NCER is planning an interdisciplinary workshop of researchers, practitioners, and decisionmakers in ecology, public health, remote sensing, and the social sciences. We will discuss the state of the science, refine research priorities, and begin discussions on how to integrate existing data into a monitoring and risk-forecasting network that aims to prevent or significantly mitigate risks of human disease and threats to biodiversity around the world.

The workshop will bring together experts from a variety of disciplines, academia, nongovernmental organizations, and management agencies from the United States and abroad, to share expertise and information and to consider new approaches to characterize the relationship of biodiversity and human health, develop tools to help monitor and forecast risks, and manage risks to health and the environment. In breakout groups, participants will address three specific tasks:

1. Case Studies on Biodiversity and Human Health

Identify case studies and disease systems that could show or test a clear linkage between biodiversity and human health. Discuss different mechanisms in which changes in biodiversity can affect human health. What are the questions that could be applied across disease (established and/or new) systems? What are the likely outputs of such research? How can they be used by decisionmakers to improve health and the environment?

2. Risk Management and Policy

Discuss risk management of environmental health problems and how to develop intervention strategies that reconcile conflicts between environmental and health concerns. This session can help address how the efforts of public health agencies to control outbreaks of vector-borne diseases can impact biodiversity. How can the mismatch in thinking between health and biodiversity experts and practitioners be addressed and resolved? What kinds of data/tools do managers need from scientists that could be useful to decisionmaking?

3. Mapping Biodiversity and Human Health

Discuss how to use Earth observation and field data to develop disease risk maps and spatial models to examine relationships between habitat alteration, biodiversity loss, changes in pathogen distribution, and the emergence and spread of vector-borne and zoonotic diseases. Disease risk maps could be used as decision-support tools, enhancing the capacity to do surveillance and risk forecasting of ecosystem and human health, and they could enable the identification of areas suitable for pilot projects to study the relationship between biodiversity change and risks to human health.

The goals of this workshop are to improve understanding of the relationship between biodiversity and human health, and to identify research priorities from a multidisciplinary perspective as well as the research outputs that would be useful for decisionmakers charged with protecting public health and the environment. Workshop organizers are interested in publishing key findings in a prominent scientific journal.

Workshop Discussion: Case Studies on Biodiversity and Human Health

September 15, 2006

Executive Summary

In co-sponsorship with Yale University's Center for EcoEpidemiology, the Smithsonian Institution, and the World Conservation Union, EPA's NCER convened an interdisciplinary forum of researchers, practitioners, and decisionmakers in ecology, public health, remote sensing, and the social sciences. The workshop discussion "Case Studies on Biodiversity and Human Health" brought together experts from a variety of disciplines, academia, government agencies, and non-governmental organizations from the United States and abroad, to share expertise and information. The workshop participants identified case studies that could test the links between biodiversity and health, mechanisms by which they could be connected, and guiding research questions that could be studied across different systems.

There are case examples in which increases in biodiversity, among reservoir hosts, vectors, and at the microbial and genetic levels, could lead to both positive and negative effects on health. The type of health effect linked to a change in biodiversity at a given taxonomic level (e.g., parasite diversity, fish community, landscape) can be determined by pathogen characteristics, community dynamics within the ecosystem, and human behavior. It is important to consider the social and economic context of human behavior. Global and local anthropogenic drivers to biodiversity change include trade and land use.

The discussion was not limited in scope to human health effects, but also included animal health and economic and social well-being. The group identified case studies that could demonstrate or test a clear link between biodiversity change and risks to health. A spreadsheet was developed listing case studies, identifying for each the taxonomic level of biodiversity that is the driver, disease/health response variable, and context/location of the system. Participants identified four categories of scientific mechanisms by which biodiversity can affect health:

- Host/pathogen density and relative abundance.
- Contact, exposure, and transmission.
- Landscape heterogeneity.
- Human susceptibility.

Conceptual and strategic questions were developed, as well as criteria for prioritizing health issues.

The group discussed the importance of crossing interdisciplinary boundaries to advance knowledge, noting that barriers in language and culture must be overcome before different methods and tools could be considered and integrated. Recommendations were made to facilitate interdisciplinary research and training through the establishment of virtual centers and institutionally based working groups.

Characterizing the relationship between biodiversity and health can reveal general principles and models that are transferable across health issues, and perhaps across spatial scales. New knowledge on how changes in biodiversity are related to health can lead to the development of models or tools to predict risks. This knowledge can inform decisionmaking to improve the management of our natural resources to protect the environment and public health. Workshop organizers are interested in continuing this discussion with participants to develop a scientific manuscript for publication.

Workshop Discussion: Mapping Biodiversity and Human Health

September 15, 2006

Executive Summary

The group was charged with developing a spatial method to study the relationship between biodiversity loss and the emergence and reemergence of infectious disease. The group identified several areas and methods for testing hypotheses about this relationship.

1. Identify specific disease systems and their associated geographic areas.
2. Combine land-use and land-cover-change data, and other surrogates for biodiversity loss, with geo-referenced disease data.
3. Investigate nonlinear, or threshold, responses via retrospective analysis. This nonlinear response could be examined for changes in biodiversity and changes in infectious disease.
4. Develop a pilot geospatial analysis and decision-support tool for specific disease systems, including use of risk mapping for purposes of early warning, to target more intensive surveillance, and to develop surrogates that explain and use false positives.
5. What are the consequences of these research issues for developing observation strategies? It was recognized that there is a need for hierarchical analyses: coarse-scale global screening could help identify areas for finer scale analyses based on indicators of change.
6. Investigate trade pathways. It is important to research how trade, tourism, and travel affect biodiversity and the transport of possible vectors.

The group proposed using wiki-based technology to capture further discussions, link to papers, data, comments, and initiate a community of practice.

Appendices

Biodiversity and Human Health: A Multidisciplinary Approach To Examining the Links

National Museum of Natural History
Baird Auditorium
10th Street and Constitution Avenue, NW
Washington, DC 20013

September 14, 2006

Agenda

8:30 a.m. – 9:00 a.m. — **Registration**

9:00 a.m. – 9:30 a.m. — **Welcome and Opening Remarks**

William H. Farland, *Deputy Assistant Administrator for Science*, Office of Research and Development, U.S. Environmental Protection Agency

Vice Admiral Conrad C. Lautenbacher, Jr., U.S. Navy (Ret.), *Under Secretary of Commerce for Oceans and Atmosphere and Administrator*, National Oceanic and Atmospheric Administration

9:30 a.m. – 10:20 a.m. — **Biodiversity Decline and Risks to Human Health**

9:30 a.m. – 9:45 a.m.	Richard Ostfeld, Institute of Ecosystem Studies
9:45 a.m. – 9:55 a.m.	Questions and Discussion
9:55 a.m. – 10:10 a.m.	Vanessa Ezenwa, University of Montana
10:10 a.m. – 10:20 a.m.	Questions and Discussion

10:20 a.m. – 10:45 a.m. — **BREAK**

10:45 a.m. – 11:35 a.m. — **Disease Emergence in Terrestrial and Marine Environments**

10:45 a.m. – 11:00 a.m.	Rita Colwell, University of Maryland
11:00 a.m. – 11:10 a.m.	Questions and Discussion
11:10 a.m. – 11:25 a.m.	Durland Fish, Yale University
11:25 a.m. – 11:35 a.m.	Questions and Discussion

11:35 a.m. – 12:00 p.m. — **Natural Hazards and Coastal Biodiversity**

11:35 a.m. – 11:50 a.m.	Phil Berke, University of North Carolina
11:50 a.m. – 12:00 p.m.	Questions and Discussion

12:00 p.m. – 12:25 p.m. — **Soils, Biodiversity, and Links to Human Health**

12:00 p.m. – 12:15 p.m.	Diana Wall, Colorado State University
12:15 p.m. – 12:25 p.m.	Questions and Discussion

12:25 p.m. – 1:45 p.m. — **LUNCH** (on your own)

1:45 p.m. – 2:35 p.m.	**Environmental Change and Disease Risk**	
	1:45 p.m. – 2:00 p.m.	Tony Goldberg, University of Illinois
	2:00 p.m. – 2:10 p.m.	Questions and Discussion
	2:10 p.m. – 2:25 p.m.	Gregory Glass, Johns Hopkins University
	2:25 p.m. – 2:35 p.m.	Questions and Discussion
2:35 p.m. – 3:00 p.m.	**International Perspective: Research on Environmental Change and Emerging Human Diseases**	
	2:35 p.m. – 2:50 p.m.	Stéphane de La Rocque, Emerging Diseases in a Changing European Environment
	2:50 p.m. – 3:00 p.m.	Questions and Discussion
3:00 p.m. – 3:50 p.m.	**Biodiversity and Medicines**	
	3:00 p.m. – 3:15 p.m.	David Newman, National Cancer Institute
	3:15 p.m. – 3:25 p.m.	Questions and Discussion
	3:25 p.m. – 3:40 p.m.	Roberta Lee, Continuum Center for Health and Healing
	3:40 p.m. – 3:50 p.m.	Questions and Discussion
3:50 p.m. – 4:15 p.m.	**BREAK**	
4:15 p.m. – 4:40 p.m.	**Applications to the Global Earth Observation System of Systems**	
	4:15 p.m. – 4:30 p.m.	José Achache, Group on Earth Observations
	4:30 p.m. – 4:40 p.m.	Questions and Discussion
4:40 p.m. – 5:05 p.m.	**Wildlife Trade and Risks to Biodiversity and Health**	
	4:40 p.m. – 4:55 p.m.	Robert Cook, Wildlife Conservation Society
	4:55 p.m. – 5:05 p.m.	Questions and Discussion
5:05 p.m. – 5:30 p.m.	**Valuation of Biodiversity Benefits to Human Health Outcomes**	
	5:05 p.m. – 5:20 p.m.	Subhrendu Pattanayak, RTI International
	5:20 p.m. – 5:30 p.m.	Questions and Discussion
5:30 p.m.	**Adjournment**	

Biodiversity and Human Health: A Multidisciplinary Approach To Examining the Links

September 14, 2006

Participants List

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Biodiversity and Human Health: A Multidisciplinary Approach to Examining the Links

Smithsonian Institution
S. Dillon Ripley Center
1100 Jefferson Drive, SW
Washington, DC 20004

September 15, 2006

Agenda

Group #1 – Case Studies on Biodiversity and Human Health (Room 3037)
Group #2 – Risk Management and Policy (Room 3031)
Group #3 – Mapping Biodiversity and Human Health (Room 3035)

9:00 a.m. – 10:30 a.m.	**Group Discussions**
10:30 a.m. – 10:50 a.m.	**BREAK**
10:50 a.m. – 12:30 p.m.	**Group Discussions**
12:30 p.m. – 1:30 p.m.	**LUNCH**
1:30 p.m. – 3:00 p.m.	**Group Discussions**
3:00 p.m. – 3:20 p.m.	**BREAK**
3:20 p.m. – 4:00 p.m.	**Group Discussions**
4:00 p.m. – 5:00 p.m.	**Summary Report-Out** Room 3037
5:00 p.m.	**Adjournment**

Case Studies on Biodiversity and Human Health

1. Identify case studies and disease systems that could show or test a clear linkage between biodiversity and human health. Discuss different mechanisms in which changes in biodiversity can affect human health. What are the questions that could be applied across disease (established and/or new) systems? What are the likely outputs of such research? How can they be used by decisionmakers to improve health and the environment?

Risk Management and Policy

2. Discuss risk management of environmental health problems and how to develop intervention strategies that reconcile conflicts between environmental and health concerns. This session can help address how the efforts of public health agencies to control outbreaks of vector-borne diseases can impact biodiversity. How can the mismatch in thinking between health and biodiversity experts and practitioners be addressed and resolved? What kinds of data/tools do managers need from scientists that could be useful to decisionmaking?

Mapping Biodiversity and Human Health

3. Discuss how to use Earth observation and field data to develop disease risk maps and spatial models to examine relationships between habitat alteration, biodiversity loss, changes in pathogen distribution, and the emergence and spread of vector-borne and zoonotic diseases. Disease risk maps could be used as decision-support tools, enhancing the capacity to do surveillance and risk forecasting of ecosystem and human health; and, they could enable the identification of areas suitable for pilot projects to study the relationship between biodiversity change and risks to human health.

Workshop Discussion: Case Studies on Biodiversity and Human Health

September 15, 2006

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September 15, 2006

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September 15, 2006

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