Examining the Links Between Biodiversity and Emerging Disease

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U.S. Environmental Protection Agency
27 April 2009

Outline

- Background
- Interdisciplinary Approach
- Leading Research Questions
- Research Projects
- Anticipated Results
  - Cost-Benefit and Policy applications

Ecosystem Services

As provided by the diversity of life on earth

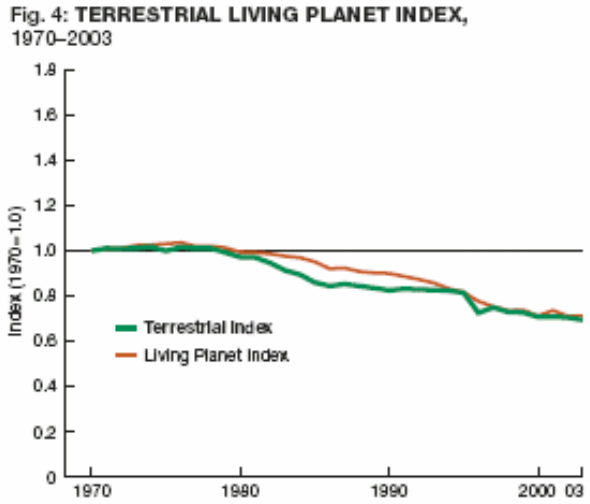
Provisioning Services	**Regulating Services**	**Cultural Services**
Food	Climate regulation	Aesthetic
Freshwater	Flood regulation	Cultural
Wood and fiber	**Disease regulation**	Recreational
Fuel	Water purification	Spiritual
Clean Air		
Medicines		

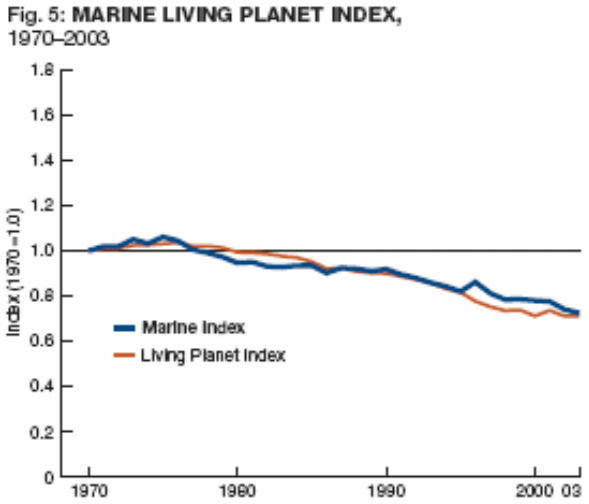
Supporting Services

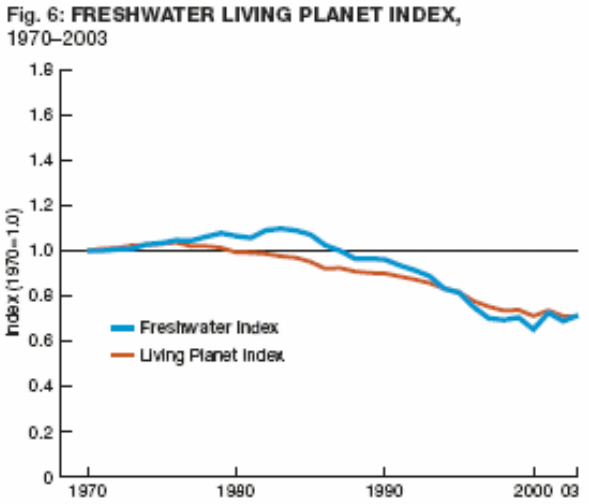
Nutrient cycling
Primary production
Soil formation

Adapted from the Millennium Ecosystem Assessment, 2005.

Biodiversity loss is accelerating

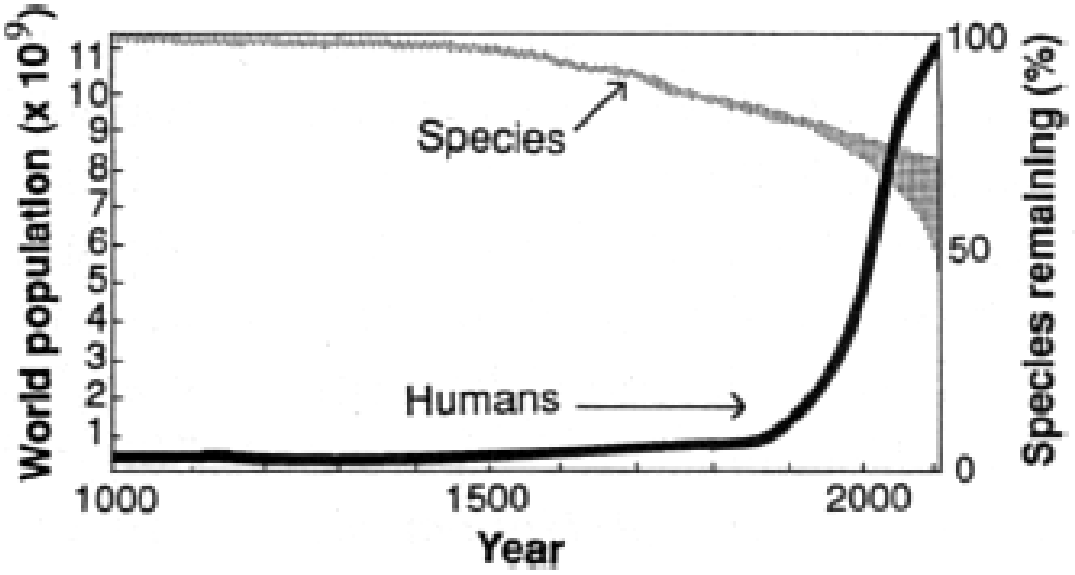






From WWF, “Living Planet Report,” 2006.

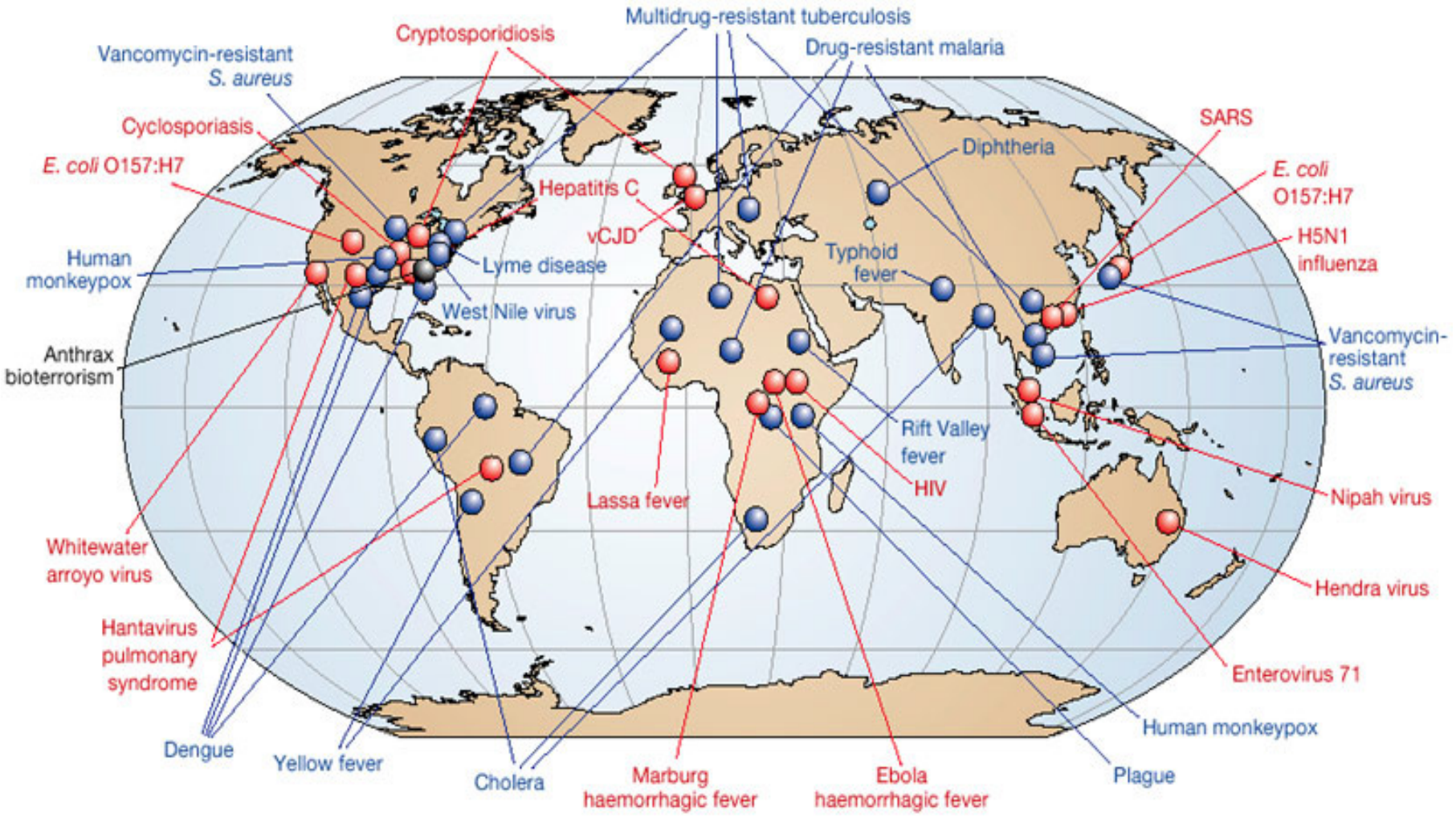
The Biodiversity Crisis



Human actions are causing a biodiversity crisis, with species extinctions up to 1000 times higher than background rates

-Pimm et al. 1995

Infectious diseases appear to be emerging and re-emerging at a faster rate

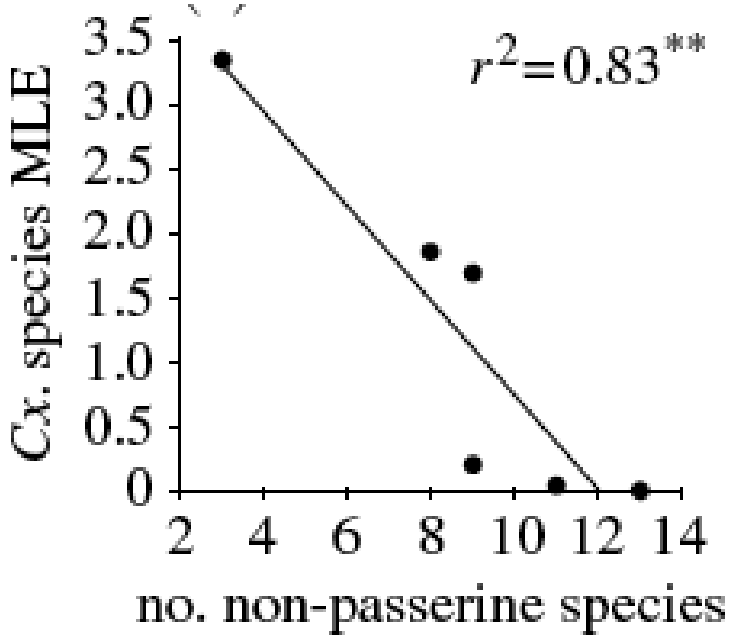


* Modified from Morens et al. 2004 *Nature* 430:242

Background "Matrix" of Infectious Diseases of Global Public Health Importance

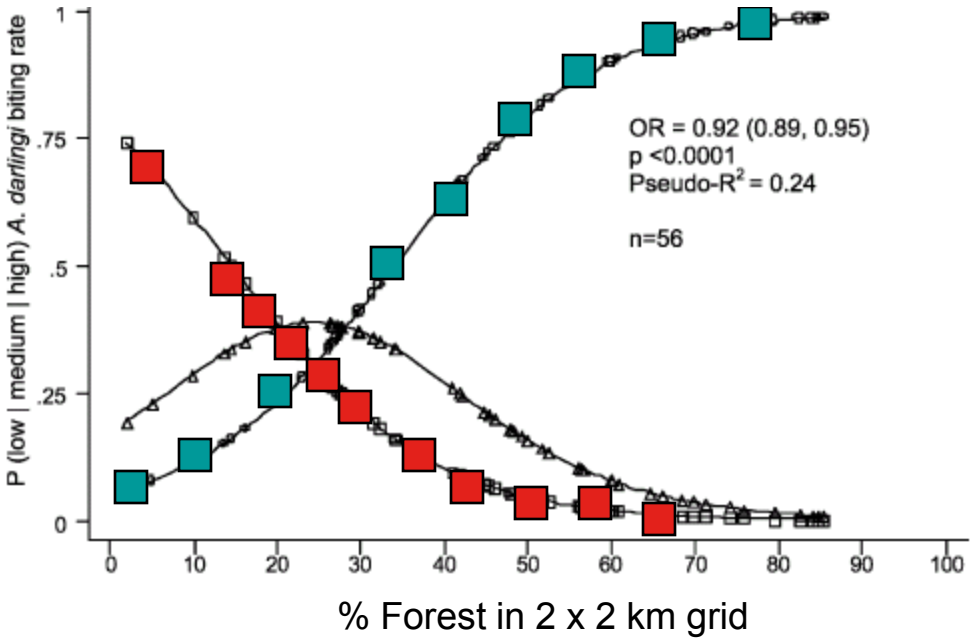
DISEASE	Estimated Annual Deaths
Respiratory Infections	4.0 million
HIV/AIDS	2.7 million
Diarrheal Diseases	**1.8 million**
Tuberculosis	1.6 million
Malaria	**1.3 million**
Vaccine Preventable Childhood Diseases (measles, pertussis, tetanus etc.)	600,000
Sexually Transmitted Diseases (except HIV)	180,000
Meningitis	**173,000**
Tropical Parasitic Diseases (trypanosomiasis, leishmaniasis etc.)	**129,000**
Hepatitis B	103,000
Dengue	**19,000**

Increasing biodiversity moderates risk of West Nile encephalitis in Louisiana



- Ezenwa et al. 2006

Deforestation and Spread of Vector-Borne Diseases



- Vittor et al. 2006

This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant #

Biodiversity-Health Research Initiative U.S. EPA

- Exploratory research funding – competitive extramural grants and interagency agreements
- Qualitative and quantitative relationships - how do anthropogenic drivers of changes in biodiversity affect the transmission of human infectious disease?
- Interdisciplinary research approach, including decision-makers
- Encourage coordination of earth observations (satellite and in-situ instruments) with field data
- International and domestic projects

Why is this Research Important?

- Root causes of disease emergence and spread should be explored to assist in prevention and mitigation
- Environmental and social factors contribute to these diseases – and environmentally-based and behavioral approaches can help reduce the disease burden
- Lack of integrated tools and approaches that link biodiversity to human health

Linking Biodiversity and Health: Research Questions

- What are the mechanisms by which changes in biodiversity affect health?
- At which taxonomic level does biodiversity affect human health? What ecological scale?
- When do we expect ecological risk to be correlated with human disease risk?
- What are the feedbacks between human behavior, biodiversity change, and human disease?
- How can global drivers like climate change and migration affect the link between the biodiversity

Summary Table of EPA's Exploratory Research Projects

	Characterizing Dilution Effect Mechanisms (Inst of Ecosystem Studies)	Plant – Animal – Mosquito Diversity and Human Perception (Rutgers)	Avian Diversity, Bioclimatic Factors, and Anthropogenic Change (UCLA)	Lyme disease Risk Map (Yale, CDC, NASA Ames, EPA)	Monitoring Mosquito Species Diversity Across a Landscape Gradient (EPA, Smithsonian)
Geographic Focus/Scale of Research	Forest plots across Duchess County, NY	Townships across New Jersey	National (USA)	National (USA)	Barro Colorado Island/Panama Canal Watershed (Panama); Khao Chong, Thailand??
Disease System of Study	Lyme disease	West Nile encephalitis	West Nile encephalitis West Nile virus	Lyme disease	Mosquito-borne diseases
Multi-Disciplinary Team Makeup	ecology, population biology, epidemiology	ecology, parasitology, ornithology, social science, environmental education, environmental managers	ecology, virology, population genetics, remote sensing	epidemiology, ecology, remote sensing, environmental managers	ecology, epidemiology, entomology, biosystematics
Strengths of the Research Study	"Dilution effect" hypothesis will be tested on a well-studied ecological-epidemiological system Much preliminary data are available and extensive study infrastructure already in place Planned interdisciplinary workshop to identify risk reduction strategies is directed to homeowners – connecting science to local residents	Attempting to quantify structural diversity, not just animal species richness Human behavioral component is innovative, attempting to link human attitudes of wetlands to disease risk Use of Bayesian methods is novel State Department of Environmental Protection (end-user) is involved in study design, execution, and implementation	Focus is on the role of bird reservoir hosts in disease prevalence Cutting edge technology to be used to evaluate virus from bird feathers and migration patterns Migratory connectivity is an important feature of study Use of earth observations on climate, land cover, and moisture for integration into the proposed distribution model	Building on an existing CDC-Yale spatial modeling project to test new hypotheses linking tick density and infection rates with new data on meteorology, mammalian and bird diversity Use of NASA Terrestrial Observation and Prediction System (TOPS) to deliver datasets from a variety of remotely sensed and *in situ* sources CDC and EPA are collaborators, helping to ensure that research results are communicated to the public and made relevant to decisionmakers	Addresses new questions about the relationship between landscape change, mosquito species diversity and pathogen diversity Provides new material for SI's mosquito barcoding initiative, and enhanced identification tools, in turn, could aid the monitoring work Partners include Gorgas Memorial Lab (entomological field work), Smithsonian (providing field sites in and outside of forest plot), EPA (decisionmaking relevance)
Expected Research Outputs	Quantitative model of disease risk Risk reduction guidelines produced by an	Understanding of how wetland plant structure can be used to estimate animal host and vector diversity relevant to health Understanding of	Distribution models which estimate infection patterns in migratory and resident birds and in humans, as well as the effects of anthropogenic	Surface map of human risk for infection from Lyme disease throughout the range of the primary vector. The map could be routinely updated using	New knowledge on the effects of landscape change on the distribution of mosquitoes and the ecological mechanisms that drive change New information can be added

Providing better information for decision-making tools and analysis

- Environmental-health policy strategies from research results
  - Guidance on individual protection
  - Best practices on land use
  - Green infrastructure
  - Integrated pest management

Providing better information for decision-making tools and analysis

- Data needs for cost-effectiveness (CEA) and benefit-cost analysis (BCA)
  - quantifying the health and ecological effects of alternative management approaches
  - estimating the values of changes in relevant health and ecological endpoints

Protecting Biodiversity, Protecting Human Health

- Environmental factors contribute to emerging diseases and environmental strategies can reduce their burden
- Development of new tools to monitor and forecast risks
- Information that can be used to value biodiversity in public health terms
- Improved communication and outreach
- Improved analysis of land use planning
- Better communication and coordination among environmental and health managers

Partners

- US Centers for Disease Control and Prevention (CDC)
- Cary Institute of Ecosystem Studies
- Rutgers University
- UCLA
- Center for Health Applications of Aerospace Related Technologies (CHAART) at NASA Ames Research Center
- Gorgas Institute (Panama)
- Yale Center for EcoEpidemiology
- Smithsonian Institution
- US Group on Earth Observations (GEO)

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Biodiversity and Human Health

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Biodiversity and Human Health:

Special Announcements

- **Photos from the Field**
  Check out four slide shows highlighting images taken from a joint EPA-Yale field study exploring the links between biodiversity, habitat change, and Lyme disease risk.
- **Could Preserving Biodiversity Reduce Disease? EPA Funds $2.25 Million to Research Connections**
  EPA has awarded three grants, totaling $2.25 million, to support research programs working to better understand and characterize the mechanisms that link environmental stressors, such as deforestation and climate change, to the loss of biodiversity and the transmission of infections diseases to people. [Read More]

EPA recognizes the importance of healthy ecosystems for our health and well-being, and conserving biodiversity is a primary way to sustain healthy ecosystems and the services they provide to us. One ecosystem service EPA is trying to better characterize is disease regulation – that is, maintaining biodiversity may protect us against emerging diseases like Lyme disease and West Nile virus.

The biodiversity-human health project complements existing domestic and international priorities to assess and manage emerging human diseases and ecosystem health hazards. But the research program is unique in its plans to link earth observations to the societal benefits outlined in the Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan EXIT Disclaimer: (1) understanding the environmental factors affecting human health and well-being, and (2) understanding, monitoring, and conserving biodiversity (GEOSS 2005).

Green Scene

Biodiversity and Human Health scientist Montira Pongsiri discusses biodiversity-human health connections in the research sponsored by the EPA STAR Research Program.

Watch Video

Research Project Search

Enter Search Term:

Go

NCER Advanced Search

http://www.epa.gov/ncer/biodiversity

pongsiri.montira@epa.gov

A Modern-Day Epidemiologic Transition?

- First during transition to agriculture (10,000 yr BP)
  - Rise in infectious disease
  - Emerging zoonotics and increased virulence of human pathogens
- Second during Industrial Revolution (19th century)
  - Shift from infectious to non-infectious chronic diseases
  - Increased water and air pollution linked to higher rates of cancer, allergies, birth defects, and impeded mental development
- Third during period of globalization and ecological collapse
  - Rise of emerging and re-emerging diseases and antibiotic resistance
  - Linked to biodiversity decline?

Interdisciplinary Forum and Workshop on Biodiversity and Human Health September 2006

US EPA, Yale Center for EcoEpidemiology, Smithsonian Institution, World Conservation Union

- **Outreach effort**
- **Interdisciplinary participation**
- **Encouraged interdisciplinary collaboration, in the U.S. and internationally**
- **Workshop discussions on case studies and mechanisms, research priorities, & types of data and models needed to map biodiversity change and emerging diseases**

Wildlife Trade and Disease Emergence

Consumption of wild animal meat
Central Africa: more that 1 billion kg per year
Amazon Basin: 67-164 million kg per year
approximately 6.4 to 15.7 million animals

Outbreaks, including SARS, have caused hundreds of billions of dollars of economic damage globally

One regulatory approach is to decrease the rate of contact among species at this interface created by wildlife trade

EPA-Smithsonian-Gorgas: Monitoring Mosquito Diversity over a Landscape Gradient (Panama)

- use appropriate tropical plots at STRI to assess the status and trends of mosquito species populations over time and evaluate whether infectious disease transmission risk is being altered in response to changes in climate and surrounding land use
- 1-year baseline study at one plot followed by longer-term monitoring and baseline study at 2nd plot for biogeographical comparison

Research Questions
Baseline Survey and Multi-plot Comparison

1) Do **mosquito species composition and abundance** over space and time vary more in richer or more heterogeneous plots?
2) What are the effects of natural and anthropogenic **disturbances** on local distributions of mosquitoes?
3) Is there a relationship between **phytotelm density and mosquito species abundance**?
4) How does **phytotelm density at the landscape scale** compare between the different plots?
5) How do **arbovirus prevalence and diversity relate to mosquito species diversity**?

Methods – Year 1

- **Where?** At BCI and nearby in disturbed site in canal zone
- **What to survey and how?**
  - Adult collections using CDC light traps and Mosquito Magnets at 1m and 20m (~canopy height) off the ground
  - Larvae from ground pools, tree holes, and phytotelmata within 2-3m of transect
  - Collect mosquitoes for ~1wk every other month over 1 year (rainy and dry seasons)
- **Taxonomic identifications**

  → preparation for museum collection

  → preparation for barcoding testing

  → preparation for arboviral analysis

Anticipated Results

- Identification of **mosquito species biodiversity** - composition, distribution, and abundance - at CTFS forest plots;
- determination of the presence of **arboviruses of public health importance** and identification of the vectors they are utilizing in distinct habitats;
- addition of new mosquito species information into ***MosquitoMap*** (mosquitomap.org);
- improved understanding of the feasibility of applying **barcodes** for fast mosquito species identifications
- **capacity building –** advance training on taxonomics, barcoding

Research Team

Smithsonian Tropical Research Institute (US-Panama)
Oris Sanjur
Jose Loaiza

Instituto Gorgas (Panama)
Rafael Samudio

Walter Reed Biosystematics Unit/Smithsonian Institution (US)
Rick Wilkerson
Jim Pecor

Natural History Museum (UK)
Yvonne-Marie Linton

Environmental Protection Agency (US)
Montira Pongsiri

Mechanisms: How can changes in biodiversity affect human health?

- Host diversity → Competent host-vector contact rates, competent host-human contact
- Structural diversity → Vector abundance and vector-human contact rates
- Structural diversity → Host and target population contact rates

Logistics

- Trap set up at canopy height with minimal contact to plot trees?
- Choosing comparison (disturbed) site with similar elevation, rainfall patterns,
- DENGUE, YF VECTORS, PANAMA SPECIES

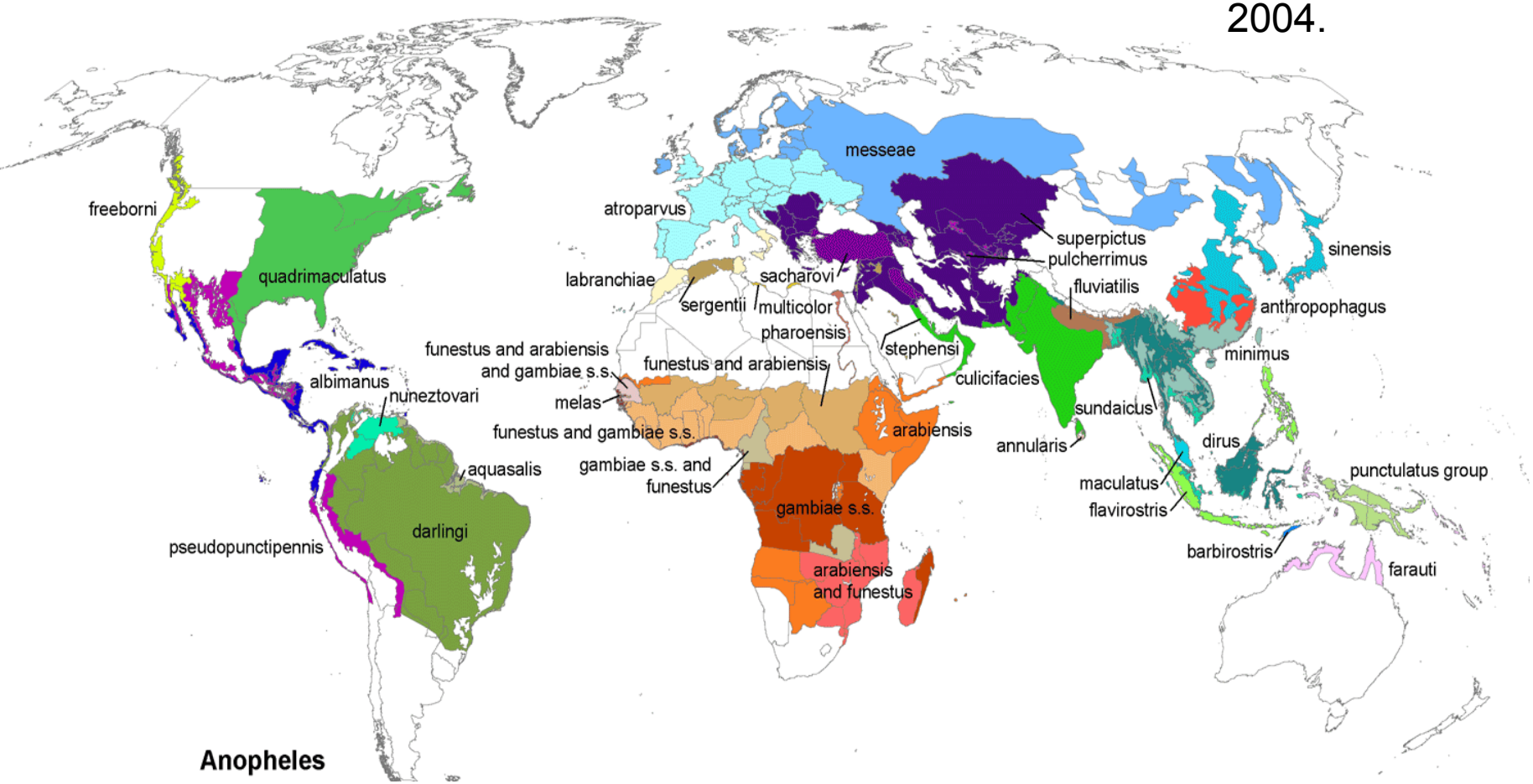
EPA-Smithsonian-Gorgas: Monitoring Mosquito Diversity over a Landscape Gradient (Panama)

- Biodiversity decline through deforestation can affect vector density and composition
- Deforestation effects microclimate changes that affect mosquito reproduction, density and survival
- How mosquito populations respond to land use and regional climate change over time can have implications for human risk of disease
- Monitoring across the landscape gradient inside and outside of a tropical forest tree plot (Barro Colorado Island, Panama)

  - **How do changes in climate and landscape affect mosquito species density, relative abundance, distribution, and composition?**
  - **Is there a relationship between mosquito species diversity and pathogen diversity?**

Global distribution of dominant or potentially important malaria vectors.

Kiszewksi et al., 2004.

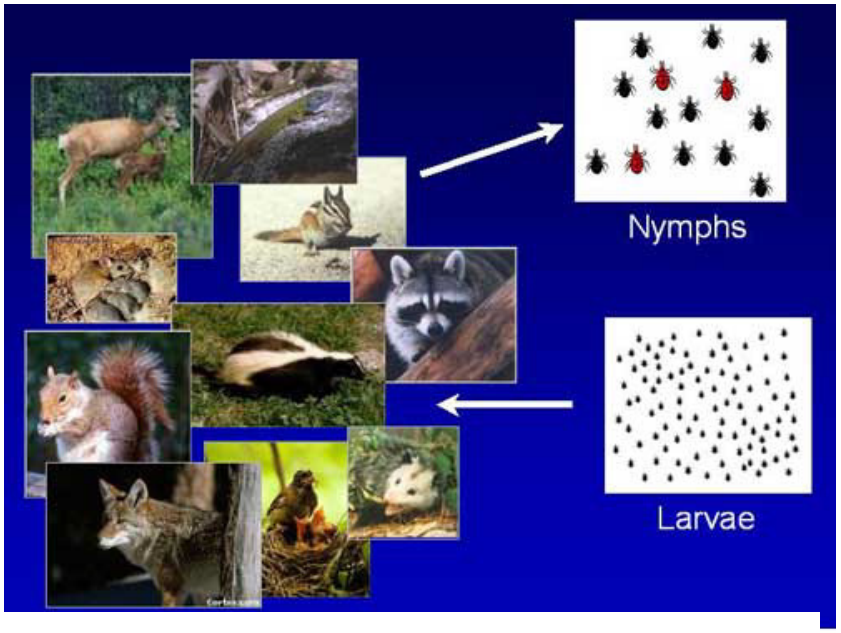


Malaria-transmitting mosquitoes are closely associated with forest communities in SE Asia and active in forest-fringed areas in Central Africa. In the Amazon, closed-canopy forests have no known malaria vectors, and open forests tend to have a lower density and diversity of

Methods

- **Where?** Across landscape gradient, including one site of maximal forest cover: four 1-hectare sites per gradient
- **What to measure?**
  - Productivity of natural mosquito habitat = number of emerging adult mosquitoes/m2/wk
  - Adult species id (taxonomic and molecular), richness and abundance
  - Environmental factors related to productivity: water temperature, presence of predator species and potential competitors, presence of emergent plants and algae, type of vegetation surrounding breeding site (forest, farm), daily rainfall (Munga et al. 2006; Patz et al. 2004)
- **How?**
  - Within each site of each gradient, use emergence traps in randomly selected habitats to collect mosquitoes for 7

Lyme disease: Dilution Effect Hypothesis



- generalist vector
- variation in reservoir competence among hosts
- horizontal transfer of the pathogen

- LoGiudice et al. 2003

West Nile: the Role of Plant Biodiversity in the Ecology of Hosts, Vectors and Humans (New Jersey, U.S.)

RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

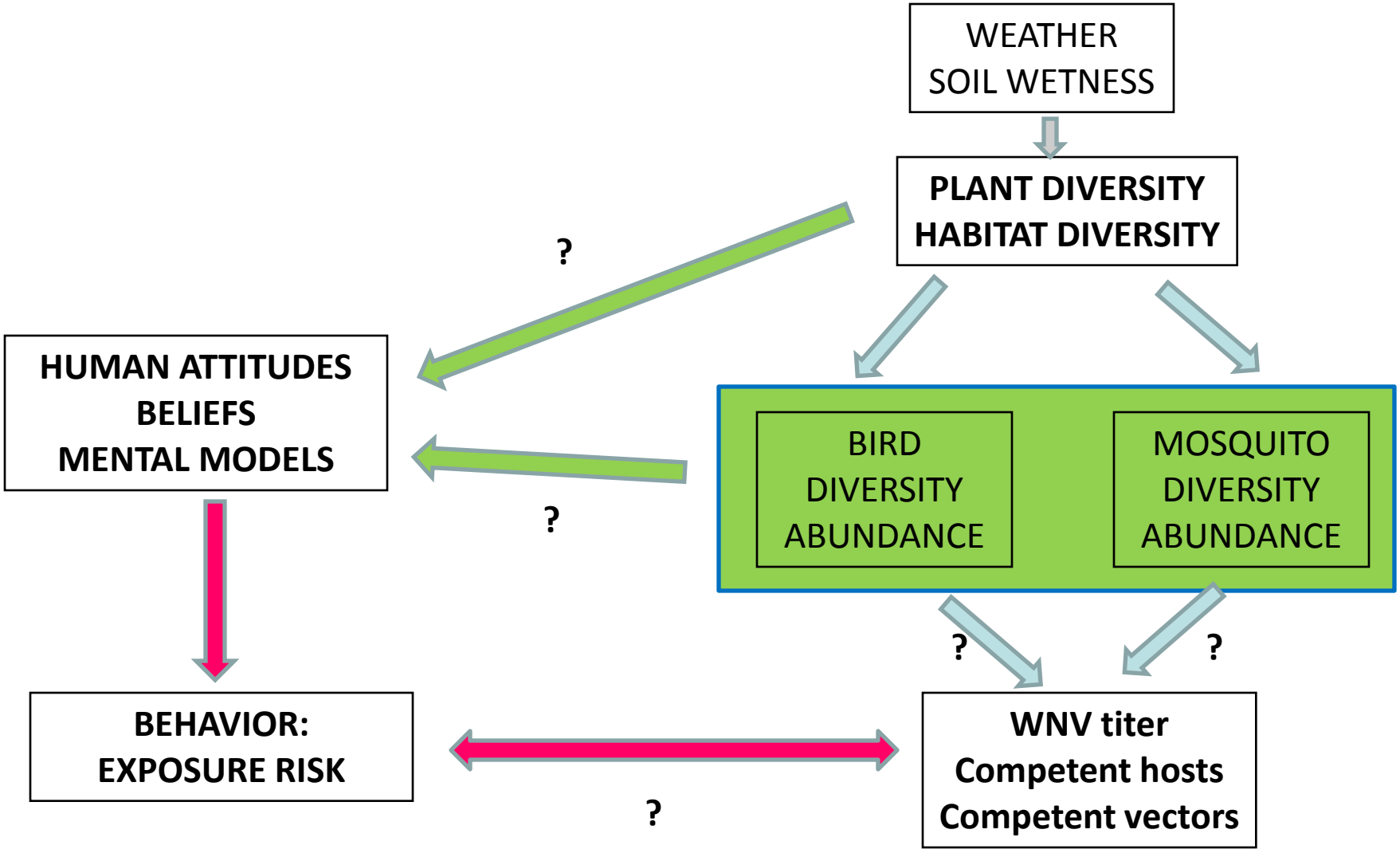
State of New Jersey
DEPARTMENT OF ENVIRONMENTAL PROTECTION

NEW JERSEY AUDUBON SOCIETY

H(a): Structural diversity is the ultimate driver of host and vector species diversity; and, plant biodiversity can influence human behavior

- Test causal relationships between plant diversity, bird diversity, mosquito diversity and viral prevalence, as well as human perceptions of diversity, values and behavior in adjacent residential communities
- Data analyses will utilize a variety of components of diversity, in addition to species richness

Conceptual Model



Mechanisms Linking Animal Host Biodiversity to Lyme disease Risk (New York, U.S.)

Cary Institute of Ecosystem Studies

- Characterize the ecological mechanisms underlying Lyme disease (LD) risk
- Manipulate host diversity and community composition by removing and translocating two competent mammalian reservoirs and one incompetent reservoir in forest fragments while monitoring abundances of other hosts

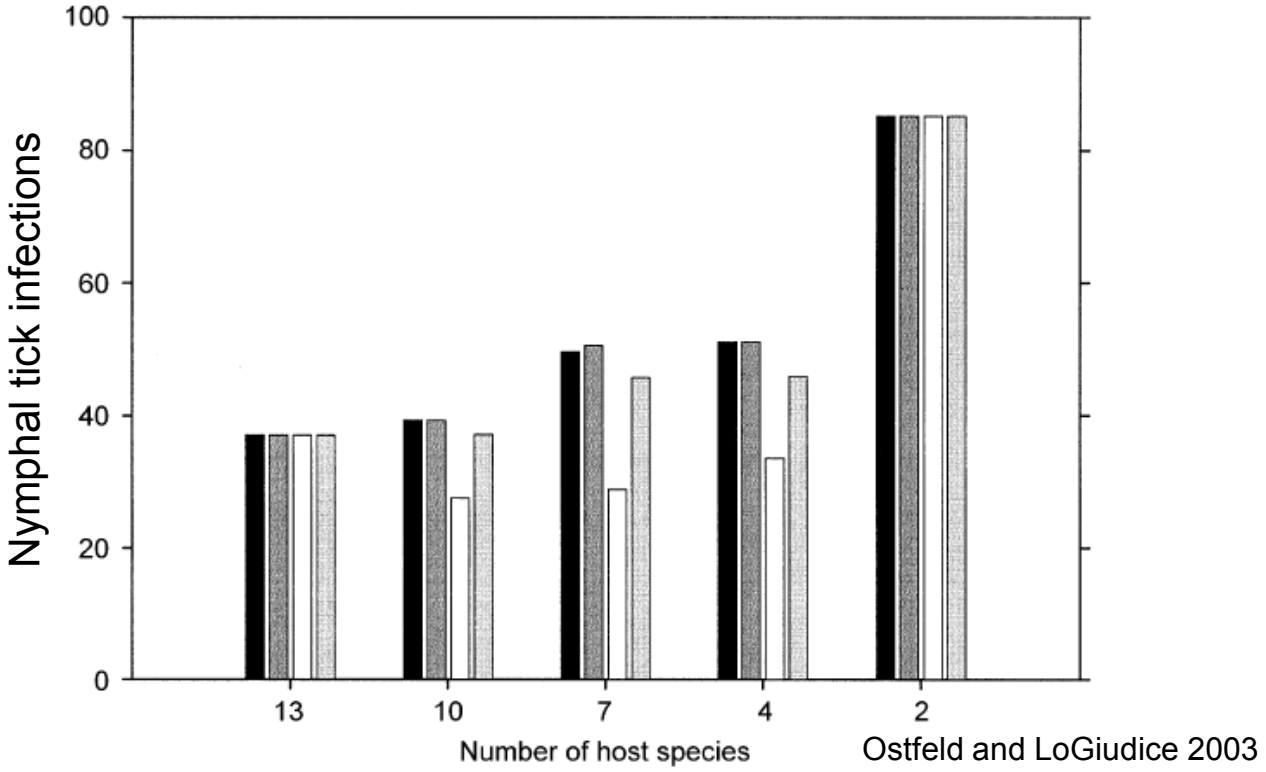
→ **Effect on tick abundance and infection rates?**

- Mechanisms by which high host diversity might reduce disease risk:
  - reducing encounter rates between ticks and the white-footed mouse
  - regulating abundance of the mouse host
  - regulating abundance of the tick

Linking Biodiversity Change to Lyme disease Risk (U.S.)

- Building on an existing CDC-Yale spatial modeling project to test hypotheses linking tick density and infection rates with new data on meteorology, mammalian, and bird diversity:
  - **Does pathogen prevalence reveal spatial patterns that are dependent on climate and landscape characteristics?**
  - **How does pathogen prevalence respond to changes in habitat structure, vertebrate communities, or other indicators of biodiversity?**
- Use of NASA Terrestrial Observation and Prediction System (TOPS)
- Surface map of human risk for infection from Lyme disease

Biodiversity and Lyme disease



Ostfeld and LoGiudice 2003

Reduced reservoir biodiversity correlates with increased risk of Lyme disease transmission to humans and may be a general rule of frequency-dependent transmission

Examining the Links Between Biodiversity and Human Health: A New Interdisciplinary Initiative

Montira Pongsiri, PhD, MPH
U.S. Environmental Protection Agency
4 December 2008

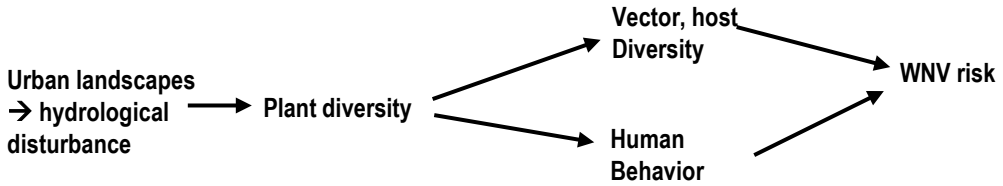


Fig. 1. Causal relationships among anthropogenic stressors, plant diversity, faunal (bird and mosquito) diversity, human behavior, and WNV risk

Role of Social Stressors and Birds on West Nile virus Transmission (U.S.A.)

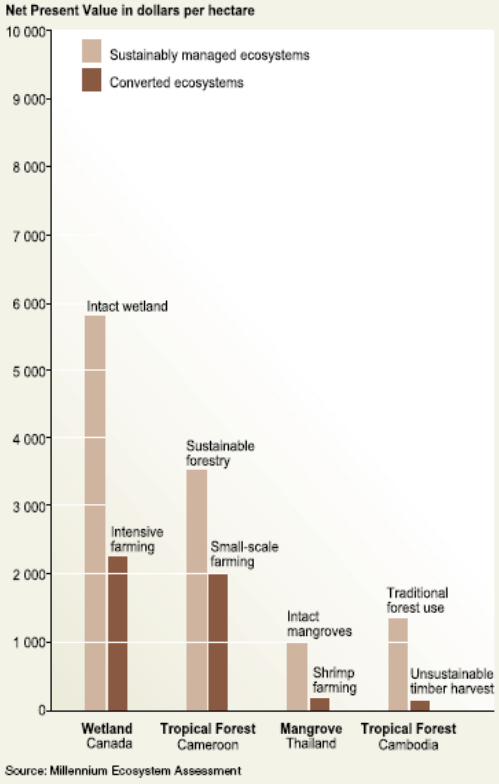
- Apr 2008- Apr 2011
- Researchers will examine the spatial and temporal patterns of West Nile Virus (WNV) in 10
- Neotropical passerines and contrast samples from pre- and post-WNV occurrence to determine whether particular species have experienced population declines.
- Based on the prevalence across selected species, they will also determine whether particular taxa are acting as species-equivalents of WNV "superspreaders."
- Bioclimatic and satellite-based remotely sensed data will be used to determine the environmental correlates of infection.
- Using recently developed distribution models (Maxent), the presence/prevalence of WNV in North America will be mapped, and researchers will examine whether changes in climate have affected distribution.
- Regarding social stressors, investigators plan to identify the possible correlates between geographical WNV hotspots and areas where anthropogenic activity has altered the environment, and contrast models of predicted prevalence with actual incidences of human infections.

Economic Impacts of Emerging Diseases

Can we afford to manage the environment?

Figure 9. Economic Benefits under Alternate Management Practices (C5 Box 5.2)

In each case, the net benefits from the more sustainably managed ecosystem are greater than those from the converted ecosystem, even though the private (market) benefits would be greater from the converted ecosystem. (Where ranges of values are given in the original source, lower estimates are plotted here.)



Source: Millennium Ecosystem Assessment

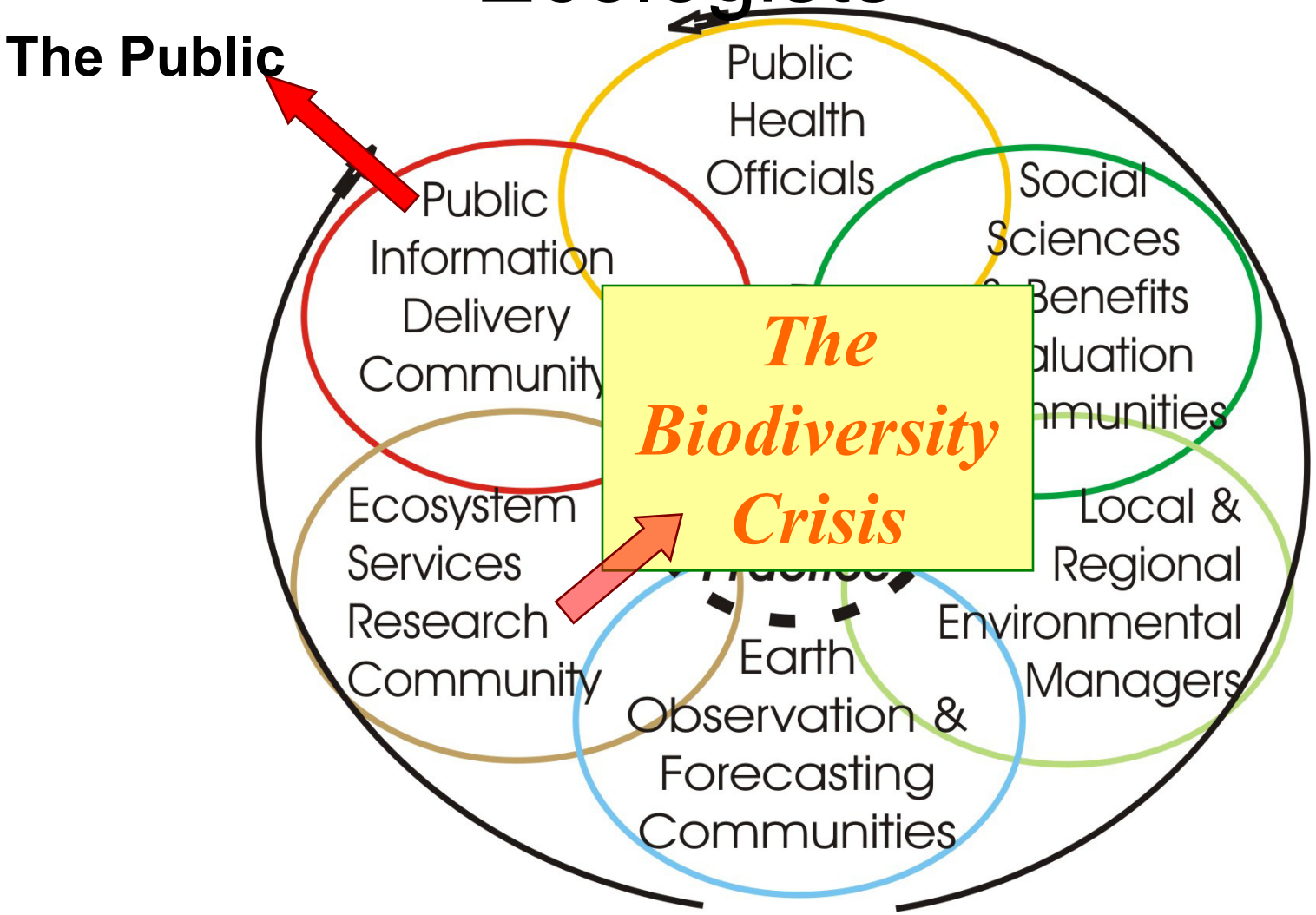
When ecosystem benefits to humans are accounted for, total economic value generated by sustainable ecosystem management may be several times greater than those from ecosystem conversion.

Ecosystems and human well-being: Synthesis.
Millennium Ecosystem Assessment, 2005

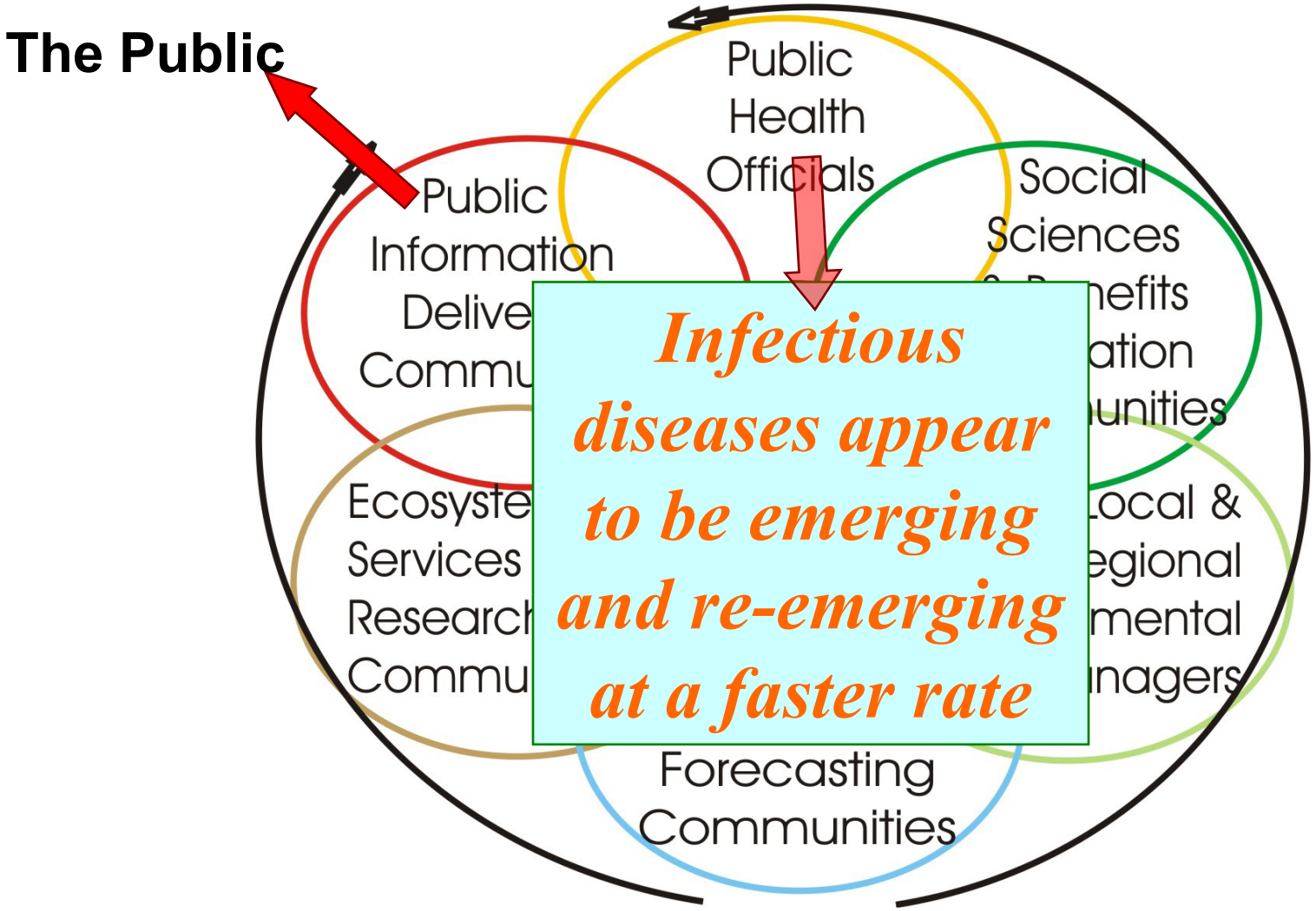
Global Earth Observation System of Systems (GEOSS)

- Being developed by the Intergovernmental Group on Earth Observations (GEO) to coordinate environmental monitoring capabilities and systems worldwide to better understand changing environmental conditions.
- Earth observations, both *in situ* and remotely sensed, are integral to understanding biodiversity and its decline over space and time and improving the capacity for analysis and prediction to inform decisionmaking.
- Organized around 9 societal benefit areas

Start with an Issue From the Ecologists



Look for the Connection with a Public Health Issue



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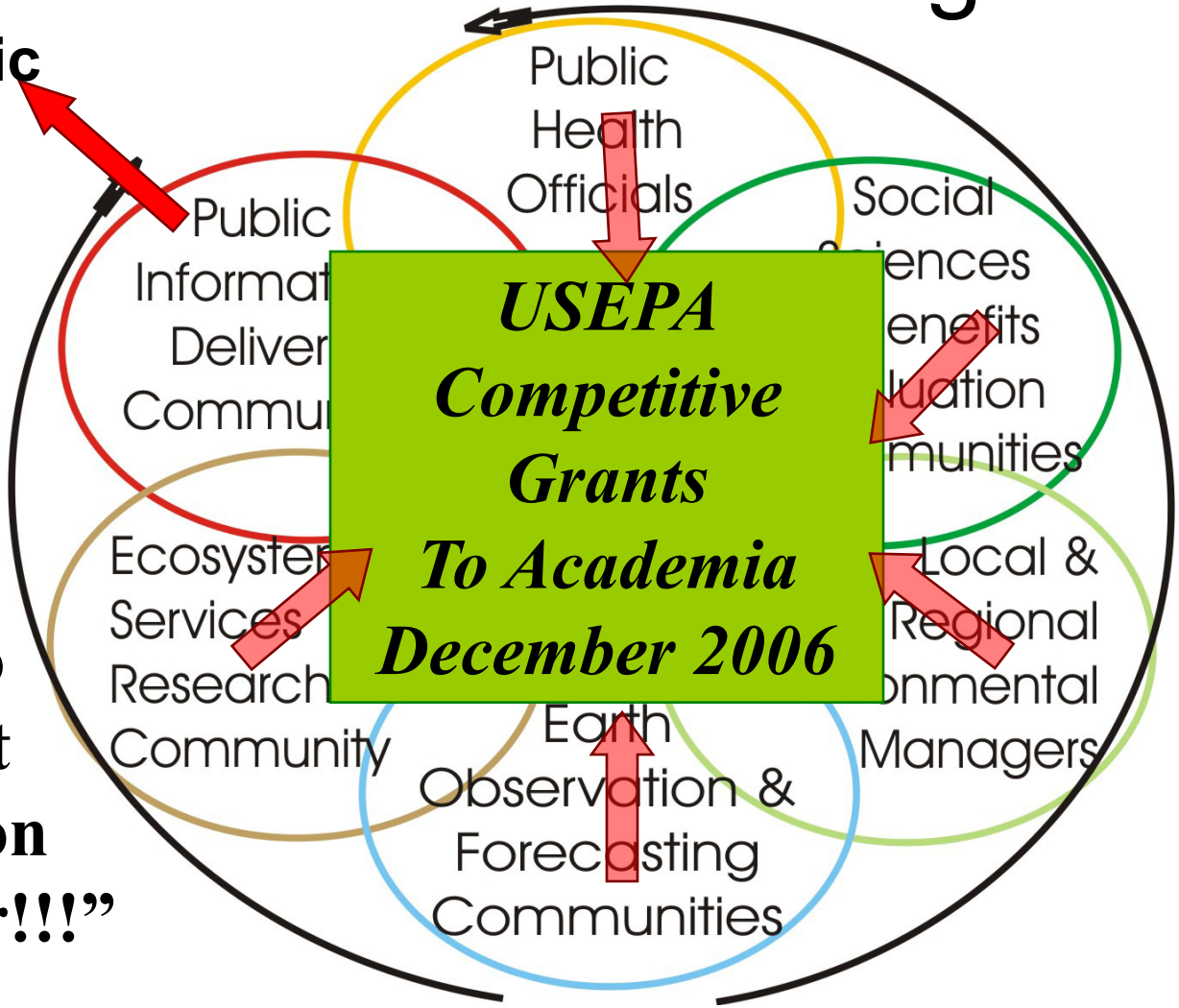
Launch an Interdisciplinary Research Program

The Public



"Those who get better at collaboration will prosper!!!"

GEOSS – applying available earth observations to study biodiversity and health

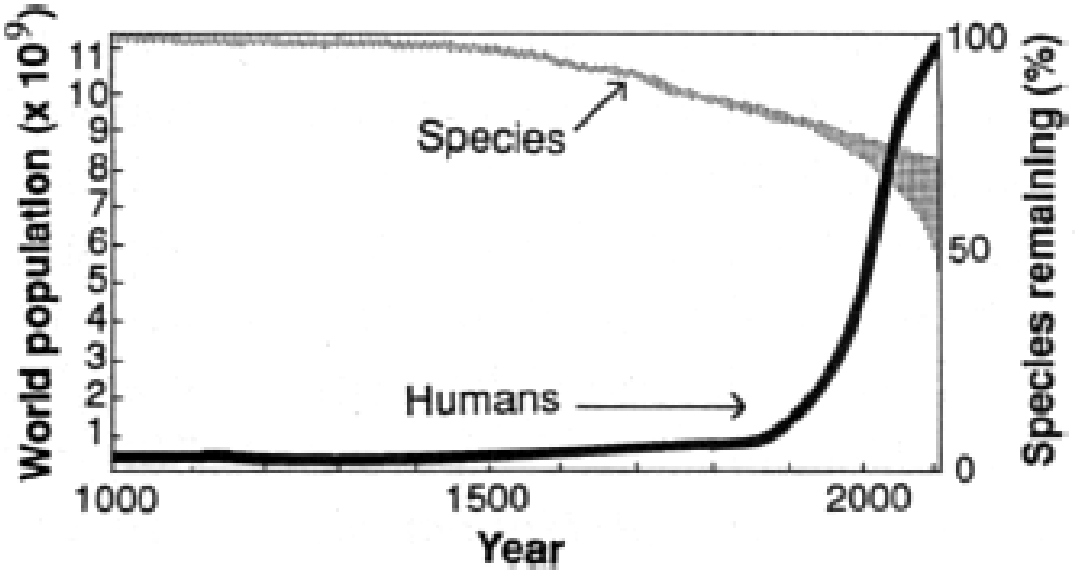
GEOSS Approach and Value-Added

- Pillars of Sustainability
- SBAs
- Links to international activities, and linkages among them

Community of Practice

- Foley figure

The Biodiversity Crisis



Human actions are causing a biodiversity crisis, with species extinctions up to 1000 times higher than background rates

-Pimm et al. 1995

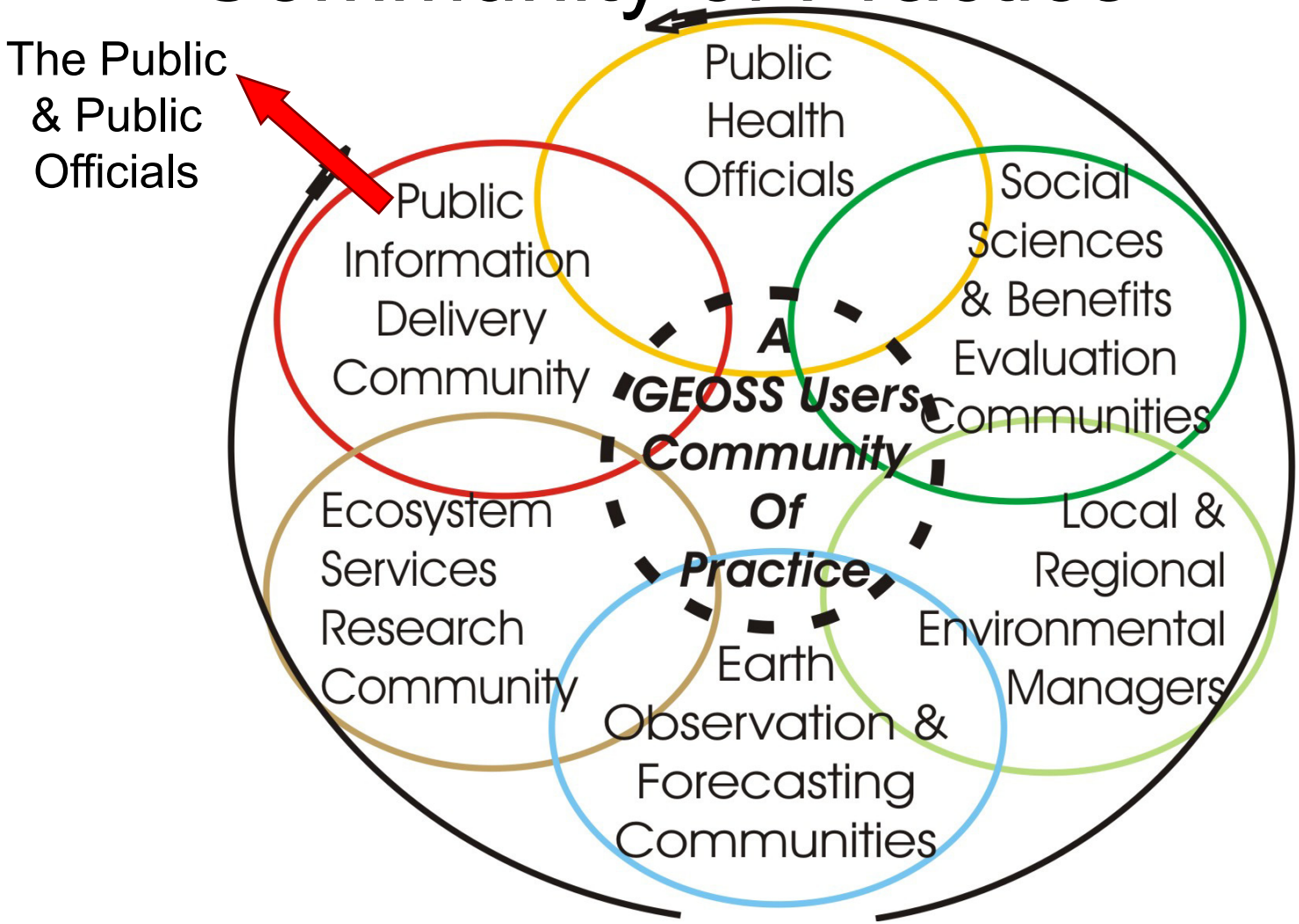
EPA Extramural Research Anthropogenic Stressors, Biodiversity, and Health

Disease Systems	Multidisciplinary	Location/ Scale	Use of Earth Observations	Research Products	Decision-Making Context
West Nile virus Plague Malaria Dengue St. Louis Encephalitis Hantavirus Pulmonary Syndrome	Ecology Epidemiology Parasitology Climatology Psychology Wildlife Biology Environmental and Health Managers	**US** – county or state level (East, West, Southwest) **Intl** – country or regional level (SE Asia, South America, Africa)	Land cover/change Plant biodiversity Habitat Climate	New knowledge characterizing mechanisms that link biodiversity change and disease transmission and emergence Risk models of disease emergence	Inform land use planning and development Inform disease control and management with minimal harm to the environment Inform how to protect landscape diversity for ecosystem services that benefit health Inform targeting of social and environmental interventions to protect biodiversity and health

Studies propose to look at how changes in diversity of vector and/or host species affect human disease risk, and how changes in diversity are influenced by anthropogenic stressors like climate change, land use change, deforestation

*Awardees to be announced in Fall 2007 after independent peer review

A Possible Biodiversity & Health Community of Practice



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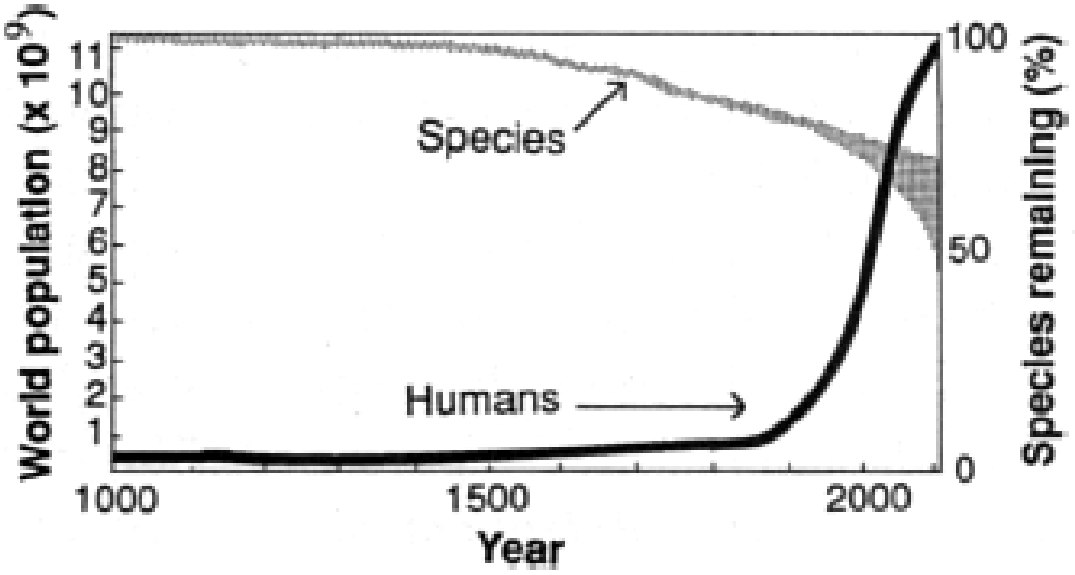

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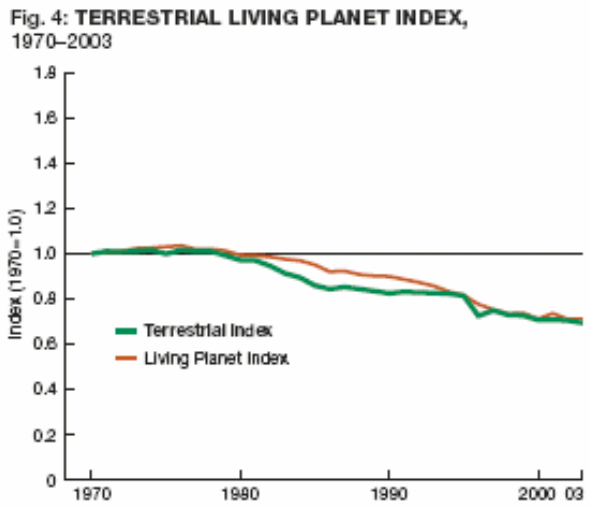
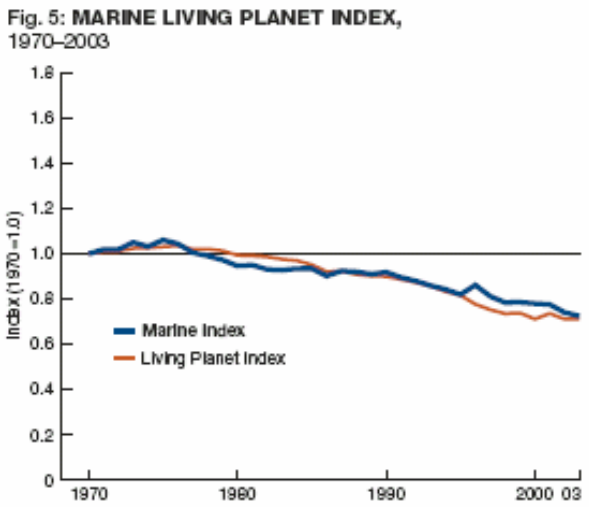
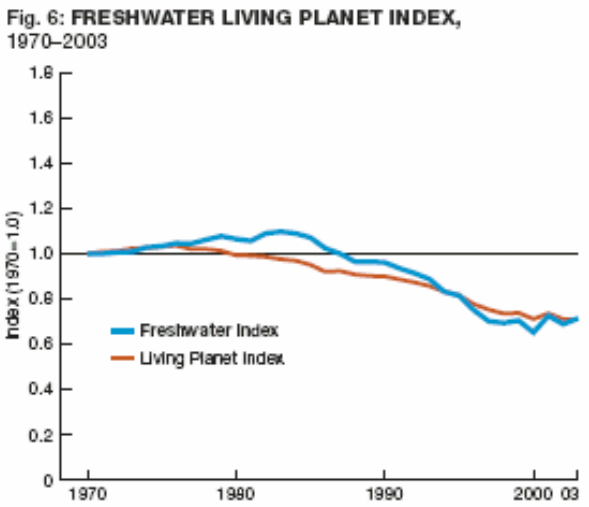
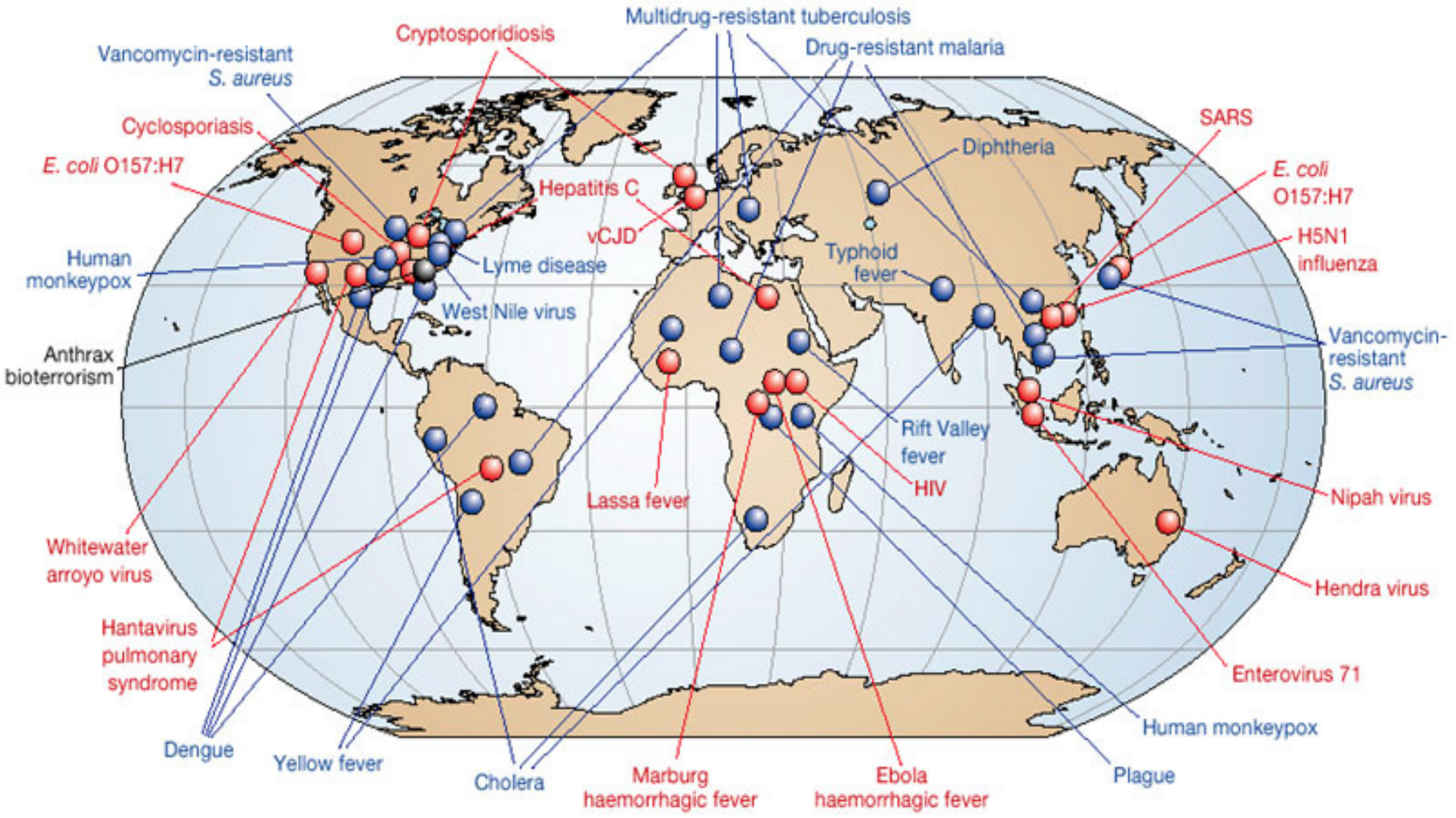






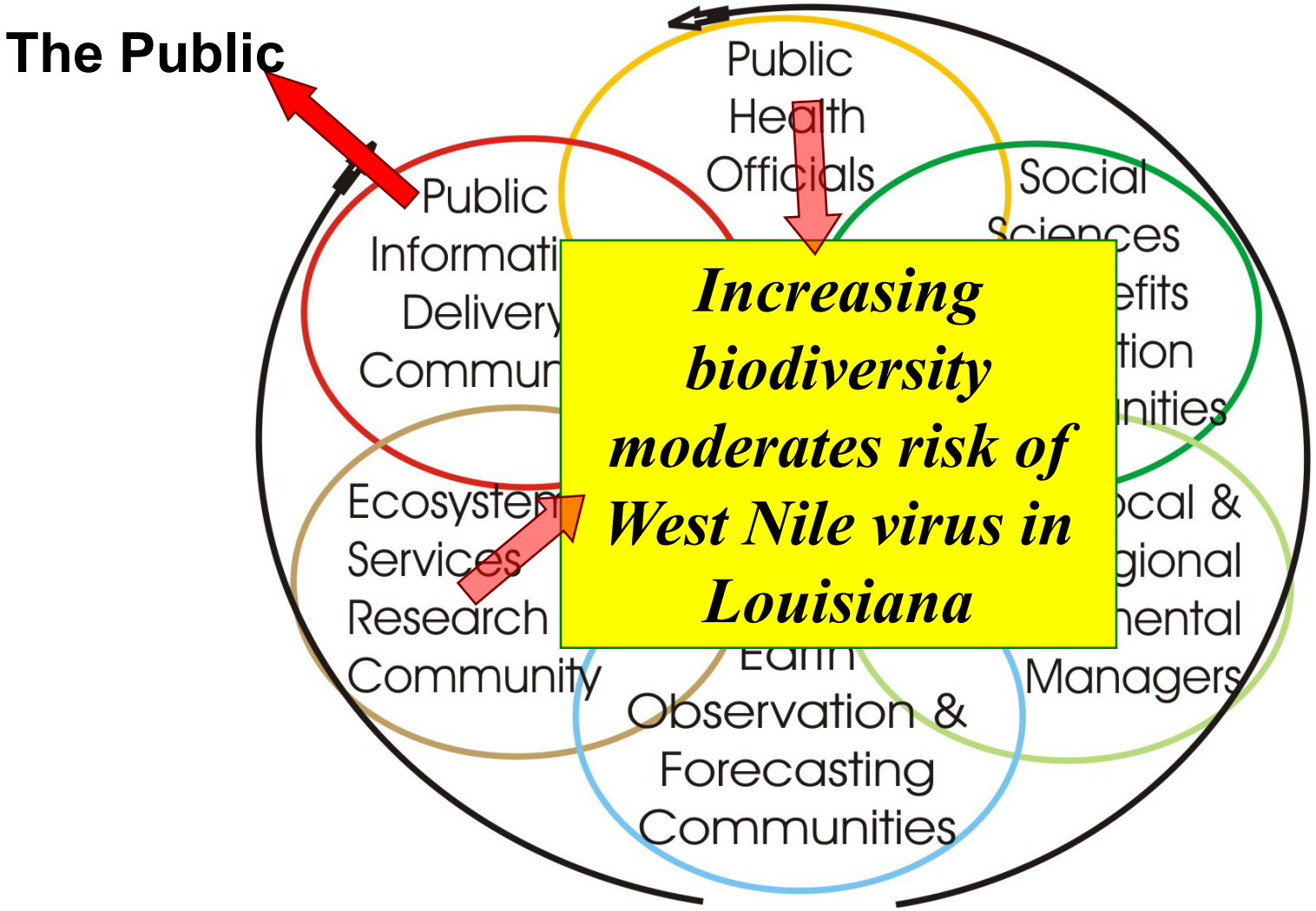
From WWF, “Living Planet Report,” 2006.

Infectious diseases appear to be emerging and re-emerging at a faster rate

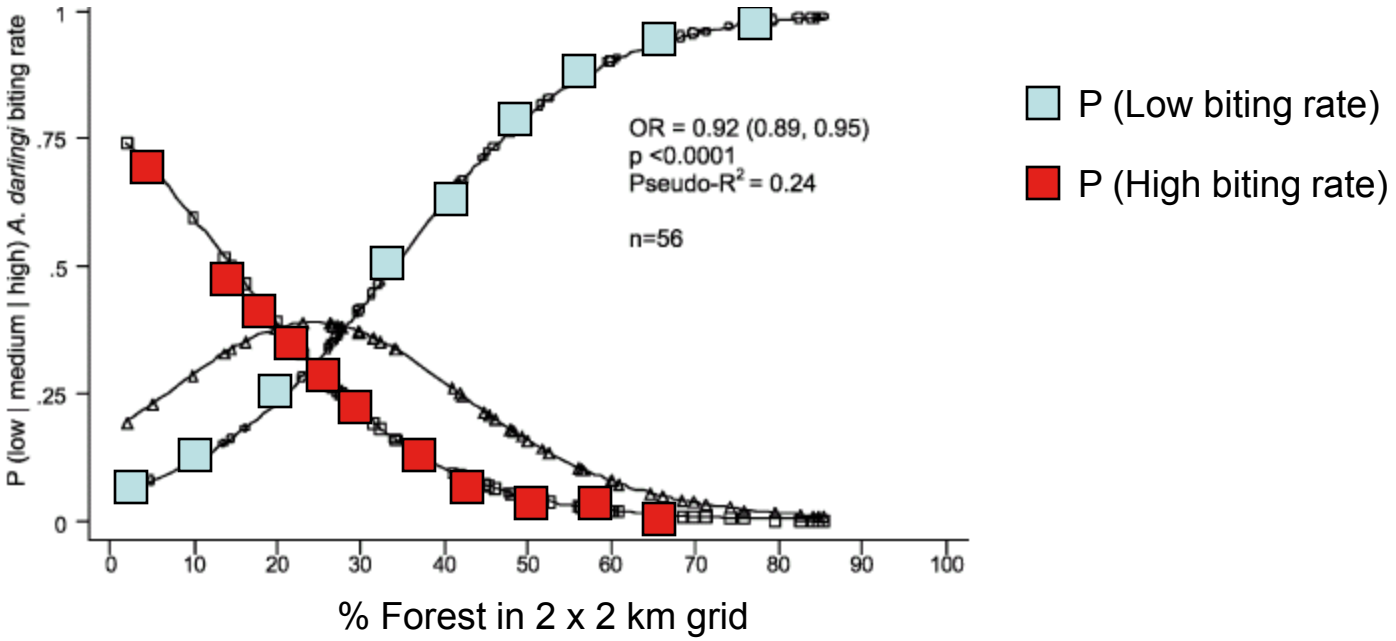


* **Modified from Morens et al. 2004 *Nature* 430:242**

Explore the Scientific Links



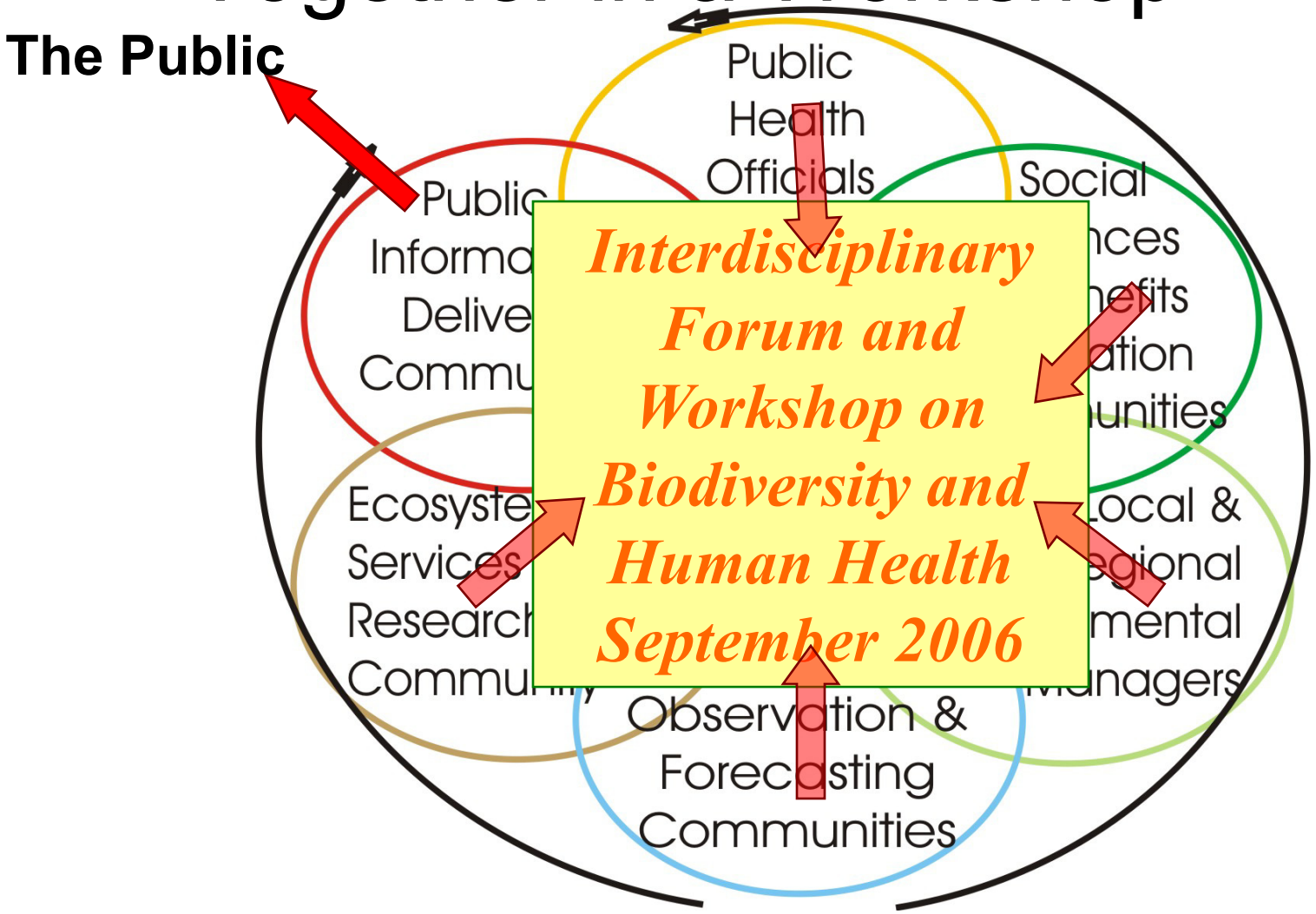
Deforestation and Spread of Vector-Borne Diseases



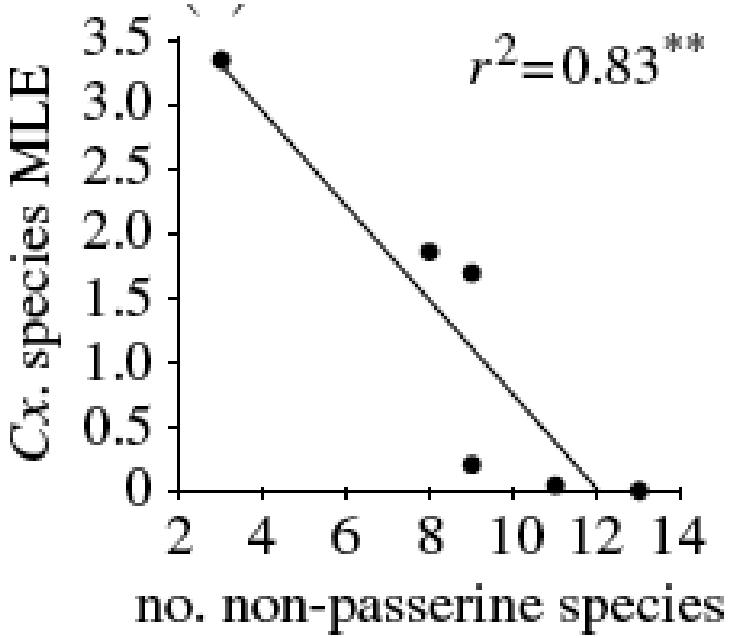
Deforested sites in the Peruvian Amazon had greater mosquito (*A. darlingi*) biting rates compared to sites with less habitat alteration.

- Vittor et al. 2006

Bring Different Communities Together in a Workshop



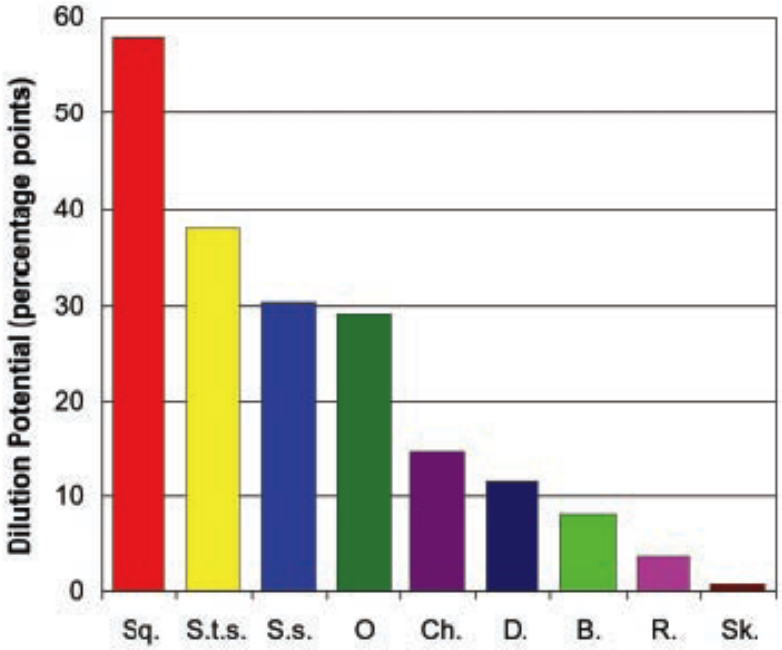
Increasing biodiversity moderates risk of West Nile virus in Louisiana



Infection rates of *Culex* mosquitoes declined with increased nonpasserine species richness

Lower infection rates among mosquitoes were correlated with lower numbers of human cases of West Nile virus.

- Ezenwa et al. 2006



LoGuidice et al. 2003

Mammalian species from squirrels (Sq) to skunks (Sk) can reduce the effect of white-footed mice, the most competent reservoir of Lyme disease, on tick infection.

90% of ticks feeding on white-footed mice become infected with Lyme bacterium

Only 15% of ticks feeding on squirrels become infected with Lyme bacterium

Species richness may be only part of the problem, abundance also