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Climate, Environment, and Infectious Diseases: A Report from the AIBS 2008 Annual Meeting

The American Institute of Biological Sciences dedicated this year's annual meeting to the challenge of Earth's changing climate and its effects on the environment, and the spread of infectious diseases. The conference, held in May in Arlington, Virginia, attracted more than 250 biologists, climatologists, and other scientists, as well as physicians and public health officials.

CHERYL LYN DYBAS

Malaria. Dengue fever. West Nile virus. Lyme disease. These and other infectious diseases are on the rise in humans. Is our interaction with Earth's environment somehow responsible? What factors are involved in the emergence and transmission of infectious diseases? How are climate change and other environmental parameters involved? These complexities have created a tangled web that scientists must soon unravel.

If biologists, climatologists, physicians, and other researchers work closely together, said Richard O'Grady, executive director of the American Institute of Biological Sciences (AIBS), "we have the potential to predict disease outbreaks and to mitigate their effects. Accelerating climate change and threats to health are now two [sides] of the same coin."

Links among the environment and infectious diseases were demonstrated in many ways and for many locations by AIBS conference speakers; they made connections between microbes, environmental events such as El Niño, and disease incidence in people. Large-scale environmental events—global climate change, land-use change and habitat destruction, and human population growth and urbanization—alter the risks of viral, parasitic, and bacterial diseases. Agricultural intensification, deforestation and reforestation, increased precipitation, and ocean warming all play a role.



*Urbanization, along with modern transportation patterns, is behind the global reemergence of dengue hemorrhagic fever. Dengue viruses and their mosquito vector (*Aedes aegypti*) have completely adapted to an urbanized lifestyle, needing only humans to complete their life cycles. Photograph: US Department of Agriculture.*

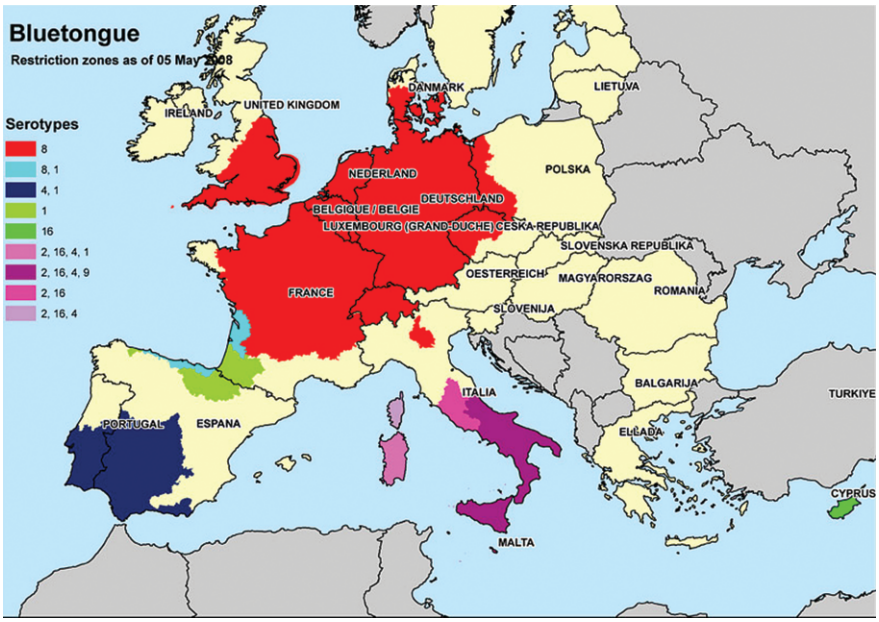
For example, in a case that might be called "CSI: Infectious Diseases and Climate Change," otherwise healthy people began dying of a mysterious respiratory disease in 1993 in the US Southwest. Tests yielded surprising results: The victims had hantavirus pulmonary syndrome, a result of a previously undetected type of hantavirus.

Research by biologist Terry Yates of the University of New Mexico, honored posthumously at this year's meeting with the AIBS Distinguished Scientist Award, showed that the outbreak was connected to the El Niño climate phenomenon, a pattern of changes in ocean circulation

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Rita Colwell is AIBS President and a professor at the University of Maryland–College Park and at Johns Hopkins University Bloomberg School of Public Health. Photograph: Carroll Photography.



*Bluetongue disease in sheep is an example of the impact of climate change on the spread of a disease. Warmer temperatures allowed the midge that is the African vector (*Culicoides imicola*) to persist in southern Europe; the pathogen then shifted to new, palearctic vectors (*Culicoides obsoletus *and* Culicoides pulicaris*) and spread through Europe. Graphic: European Commission.*

and atmospheric weather. Increased rainfall led to more plants, more mice, and more opportunities for people to come into contact with the rodents' droppings and urine, which contain the virus. Named for the Hantaan River in Korea, hantaviruses were known to spread from mice to humans in Asia and Europe, but until the 1993 outbreak, hantaviruses had been seen only outside America.

"We can no longer discuss infectious diseases simply as those that affect the US, or that affect New York City, or Washington, DC," said scientist and cholera expert Rita Colwell, of the University of Maryland and Johns Hopkins University Bloomberg School of Public Health. "Infectious diseases that arise in Africa or in Asia reach the United States, as evidenced by the SARS [severe acute respiratory syndrome] episodes," she said. "The connections to the environment are very dramatic. For example, the origin of SARS was tracked to bats in caves in Asia."

Colwell, who is also the president of AIBS, spoke of cholera as a disease not just restricted to Bangladesh or India but prevalent also in Latin America and Africa. The environmental burden of disease falls on those least prepared to deal with it, she said. Countries in Africa and in Asia, where populations are large and poverty is high, are particularly affected, as shown in studies by the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia. Dealing with the effects of climate change on infectious disease falls—so far—mostly on these populations.





Terry Maple (left) is president of the Palm Beach Zoo and coauthor of A Contract with the Earth. *James Hansen (right) is director of the NASA Goddard Institute for Space Studies. Photographs: Carroll Photography.*

How long will it be before the rest of the world follows suit? That depends, Colwell believes, on decisions we make now about our environmental future. Climate change poses risks to ecosystems and the life support they provide to people, and to all animals and plants on Earth. The bottom line, AIBS meeting participants agreed, is that to safeguard

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Durland Fish (left) is an epidemiologist at Yale University. Howard Frumkin (center) is an internist and environmental and occupational health specialist at the Centers for Disease Control and Prevention. David Rogers (right) is an ecologist at the University of Oxford. Photographs: Carroll Photography.

human health, we must live within our planet's environmental limits.

The environmental century: A world beyond fossil fuels?

Terry Maple, president of the Palm Beach Zoo in Florida, spoke of the premise of the book *A Contract with the Earth,* which he wrote with Newt Gingrich. Maple called ours "the environmental century." Green investments are growing, he said, and we need to address what he called the overwhelming issues facing life on Earth in the near future. Through their book, Maple and Gingrich hope to appeal to the public to open up dialogues and debate issues.

Looking at innovation as a solution to climate change is a promising path, Maple said. "If we get serious about innovation, we're going down the road America is good at. We'll be selling this technology to the people we're now buying oil from." For example, he discovered that almost no solar power projects exist in the state of Florida. Through his efforts, the Palm Beach Zoo is joining with Florida Power and Light to build a facility that's nearly half solar powered.

An engaged and informed populace and finding new energy sources are the only answers to the challenges we face, Maple and Gingrich believe. Answers will come not a moment too soon, many at the meeting said. Global warming, say climate and health scientists, is beginning to set off a worldwide "domino effect."

"In the story of Earth's recent climate, we have all the characteristics of 'the perfect storm,'" said climatologist James Hansen, director of the NASA Goddard Institute for Space Studies. "Among them is that the primary greenhouse gas we're putting into the atmosphere by burning fossil fuels, carbon dioxide, lasts a very long time. A large fraction will stay in the air for several centuries."

What level of carbon dioxide is an imminent threat to life on Earth? "The dangerous amount of carbon dioxide is less than what's there now," Hansen said. "We've increased carbon dioxide to 385 parts per million. We're going to have to reduce it to at least 350 parts per million."

A third of the warming in the last century has occurred over the past 30 years. Isotherms are moving forward at a rate of some 60 kilometers with each passing decade. If we continue business as usual, Hansen believes, that rate will double in the next century. "The most important thing in the short term," Hansen said, "is to deal with coal, the biggest source of carbon dioxide. I think if we addressed this, and got the process going in the right direction, there would be positive feedbacks in the social system that could, in fact, take us to a world beyond fossil fuels." We can't double or triple the amount of carbon dioxide in the atmosphere, he said, "or we're going to produce a completely different planet."

Infectious disease risks and public health: The climate factor

"Unlike directly transmissible disease between humans, zoonotic and vectorborne diseases are very much dependent on the environment, especially climate," said biologist Durland Fish, director of the Yale University Center for EcoEpidemiology. Fish focused on Lyme disease as an example.

Lyme disease was discovered in the early 1970s in Lyme, Connecticut, but it occurs throughout much of the United States and in Europe and Asia. Lyme disease risk remains highest in northeastern US states like Connecticut and Rhode Island. "There's been a lot of speculation about what's going to happen with Lyme disease and climate change," Fish said. "We could have more severe disease at more northerly latitudes."

Environmental change and reforestation have resulted in the epidemic of Lyme disease, scientists believe. A century ago, there were no deer—nor was there Lyme disease—in southern New England. In the absence of deer, deer ticks can't survive. It's only since reforestation and the subsequent proliferation of deer, Fish said, "that Lyme disease has been able to expand its range." The changing environment, he said, has everything to do with changing human disease risk.

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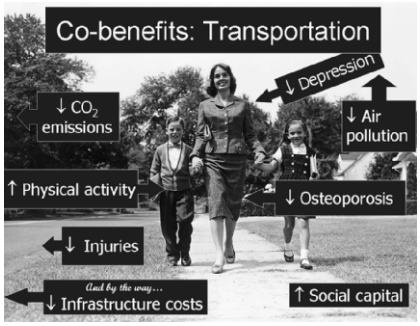
Stephen Morse (left) is an epidemiologist at Columbia University Mailman School of Public Health. Andrew Dobson (center) is an ecologist at Princeton University. Duane Gubler (right) is a tropical disease specialist at the University of Hawaii. Photographs: Carroll Photography.

"We're witnessing the emergence of a different world than the one in which our grandparents grew up," said Howard Frumkin, a physician and director of the National Center for Environmental Health at the CDC. "The world is changing almost before our eyes, including the health burden of climate."

Heat waves in cities, said Frumkin, have become more common as the climate warms. "We know who in cities is the most vulnerable: the elderly, people who are shut-ins, people who live on upper floors, people without air conditioning, people on certain medications that impair the ability to dissipate heat." Heat waves are an example of a public health problem related to climate change that physicians know how to handle. Through simple buddy systems, people are brought to safety in refuge centers.

Infectious diseases are much harder to deal with. As tropical climates expand their ranges, tropical diseases may march along in lockstep. "Sometimes this is predictable," Frumkin said, "and sometimes not." He cited dengue fever as an example of predictability. Climate modeling has been used to forecast an extension of dengue fever in various parts of the world. "Sure enough, a decade after that climate model was run," Frumkin said, "we're seeing headlines about the expansion of dengue fever."

Scientists need to take existing models that describe climate system changes and



There are many co-benefits to adapting to climate change. This parent walking her children to school helps reduce air pollution by not driving, and all three benefit from the physical activity, the reduced risk of injuries from car crashes, the social capital of greeting neighbors, and more. Graphic courtesy of Howard Frumkin, CDC/ATSDR.

Earth system changes, then scale down and extend them so they can forecast health outcomes and implications of climate change, Frumkin believes. "Then we need to develop plans to protect the public, test those plans using research protocols so we know what works best, and ultimately implement steps to protect public health."

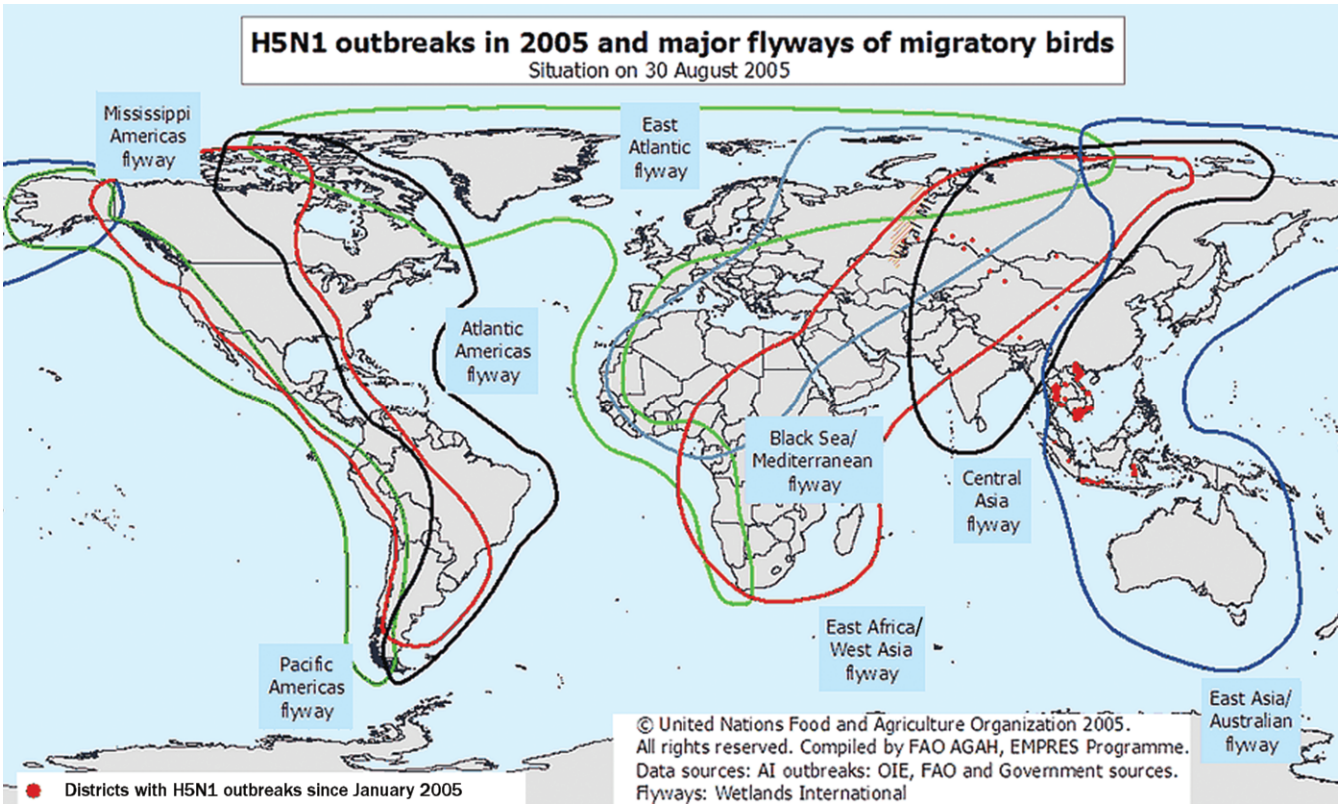
"If everything is connected," asked ecologist David Rogers, of the University of Oxford, "how can we sort out cause and effect?...How many 'inconvenient truths' are there? Is there something else we should know about?" Rogers questioned whether climate change may already have had an effect on some diseases. For that, he said, the disease must have changed "in the right place, at the right time, and in the right direction, according to our understanding of the relationship between climate and disease." In the case of malaria in East Africa, he believes, most highland areas will become climatically suitable for the disease in the near future. Evidence exists that some of those regions already harbor it.

Rogers also cited a rise in the number of human cases of tickborne encephalitis in the Baltic states from 1970 to 2005. "Are they due to global warming?" he asked. The answer lies in many complex variables, he believes, not in climate change alone. In Lithuania, for example, economic changes in total employment, agricultural changes in number of cattle, environmental changes in tick abundance, and other factors play an important role. We have a distance to go, Rogers said, in understanding the factors involved in the spread of infectious diseases. Only when we do can we say how much of that advance is a result of climate change.

The challenge ahead: Predicting the emergence of infectious diseases

Ecological changes are important for providing new opportunities for pathogens to reach the human population or to cross species, said scientist Stephen Morse

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Will migratory birds continue to follow traditional flyways as the climate changes, or will they adapt and perhaps in the process transport avian influenza to new locations? Graphic: UN Food and Agriculture Organization.

of Columbia University's Mailman School of Public Health. "A problem that has bedeviled all people who attempt to predict the effect of changing climate on infectious diseases," he said, "is that the specific scenarios—what diseases will move where—depend greatly on exact changes in climate."

Avian flu, Morse said, may or may not be the next pandemic strain, but it's of concern because there have been human cases and limited human-to-human transmission, almost all of them associated with domestic poultry. What effects might climate have on avian influenza? Migratory birds that interact with infected poultry follow age-old flyways for now, but will these birds continue to use those flyways when climate changes? Or will they change their pattern? "I suspect they will adapt," Morse said, "just like other living things, to find their 'comfort zone.'"

To answer questions about climate and disease, he said, "we need to understand a great deal more about seasonality and related factors. Specific prediction will depend on knowing specific conditions."

As the world gets wetter or warmer, how is that going to affect disease predictions? asked biologist Andrew Dobson, of Princeton University. "For most diseases, there is likely to be a seasonal driver." It gets complicated, Dobson said, "because seasonal cycles interact with the natural dynamics of disease."

Cholera and malaria are the poster children for looking at the effects of climate change on disease, he said. "With cholera, we can develop models showing that climate variability, particularly El Niño, drives cholera dynamics in Bangladesh." If scientists ignore El Niño, he continued, they won't do a very good job of predicting diseases; if they include it, they still may miscalculate because they forgot to include all the details of immunity. "Unless you know how many susceptible people are out there, you don't know how the population will respond."

Scientists looking at climate and malaria in Africa have noted a small change in temperature from 1950 to 2000, an increase of about 3 percent. "If you use that temperature change to drive a model for the dynamics of the [mosquito] vectors, then that 3 percent change results in a 30 percent increase in the number of vectors," Dobson said. "A 30 percent increase in vector density is likely to give you a significant increase in malaria."

More than one variable needs to be considered, he believes. There's the evolution of drug resistance. There's biodiversity. "The more biodiversity, the more it's protecting us from, for example, mosquito-transmitted diseases," Dobson said. "That's relevant to climate change, because as you go from the tropics to the temperate zone, you have less and less biodiversity, which means that diseases can focus more on humans."

The dynamics of all these interactions are complex mathematical problems. "It's not rocket science," Dobson said. "It's much harder."

And it all started long ago. Sometime in the past, "humans working in the forest brought the dengue virus into

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villages, where epidemics first began," said scientist Duane Gubler, of the University of Hawaii John A. Burns School of Medicine. But because human populations were small then, the epidemics didn't persist. "The viruses burned through the villages and disappeared," Gubler said. Then as port cities around the world developed, and as mosquitoes were transported and infested those port cities, an urban epidemic cycle began.

The mosquito *Aedes aegypti* is the principal vector of this disease. It's a "highly domesticated mosquito," Gubler said. "It prefers to feed on humans. It prefers to live in houses with humans—and not anywhere else."

In the early 1980s, scientists saw a dramatic geographic expansion of both the viruses and the vectors. "As we go into the 21st century," Gubler said, "dengue has become one of the most important emerging tropical diseases."

The combination of urbanization, modern transportation, and general globalization, along with increased movement of people, animals, and commodities, is perfect for moving these pathogens around, Gubler said. "Our single biggest challenge is to do something about the movement of vectors and pathogens by modern transportation. And we need a better understanding of disease ecology because most of these diseases won't have a drug or a vaccine."

New approaches for a different world

The malaria world is changing dramatically and rapidly, said Stephen Hoffman, chief executive officer of Sanaria, Inc., in Rockville, Maryland. Hoffman is a physician and tropical infectious disease specialist who, with colleagues at Sanaria, is working to develop the first successful malaria vaccine.

"We go to work every day with one dream and one dream only: to develop a malaria vaccine to prevent millions of deaths from malaria," Hoffman said. "Malaria is responsible for more deaths in children than any other infectious agent. More than 300 million people will suffer clinical attacks of malaria during the next year. I've heard estimates recently that it's up to one billion." At least 70 percent of the illnesses will occur in sub-Saharan Africa, where 90 percent of malaria-related deaths occur, most of which are children under five years old.

"Malaria not only has a huge health impact," Hoffman said, "it also has a huge economic impact. It's the leading healthcare expenditure in most of Africa. It's a major cause of poverty, and poverty enhances disease. It's been estimated that at least 10 [billion] to 12 billion dollars are lost annually to malaria in Africa."

Malaria is not only a disease of children in remote villages in Africa. Tens of millions of travelers from North America, Europe, Australia, the Middle East, and East Asia visit areas of the world with malaria every year; some 30,000 contract the disease. "Five to ten million American travelers are at serious risk annually, with equivalent numbers for Europe," Hoffman said.

Sanaria was formed five years ago with the mission to develop, license, and release a vaccine based on an attenuated version of the malaria-causing parasite *Plasmodium falciparum.* "The vaccine, we hope, will prevent infection with this parasite in greater than 90 percent of the recipients for at least six months," Hoffman said.

The vaccine development method at Sanaria is different from other approaches. The company is using a live, attenuated, whole-organism vaccine; other efforts have been "subunit recombinant" (a subunit apart from the entire infectious agent is used, and the vaccine is made recombinantly in the laboratory). Sanaria is now in the process of manufacturing its malaria vaccine for clinical trials, first in the United States, then in Africa.



Stephen Hoffman is founder and chief executive officer of Sanaria, Inc. Photograph: Carroll Photography.

"The road to success has lots of potential potholes," Hoffman said, but he believes that there will be a vaccine for malaria in five years. "I can hear footsteps behind me, so we all work every day to try to prevent the 3000 children who are dying from malaria today from dying."

In her AIBS annual meeting closing remarks, Colwell stated: "Interdisciplinary approaches will be required to address these critical problems of the 21st century. They're international, in that we will need to work together to develop a global understanding of these diseases, and also of global public health measures to be taken in a time of climate change and of societal change."

Billions of people are depending on the answers.

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