Climate, Ecology, and Human Health

By Paul R. Epstein

Epidemics are like sign-posts from which the statesman of stature can read that a disturbance has occurred in the development of his nation--that not even careless politics can overlook.

Dr. Rudolf Virchow, 1848

There are many determinants of health and well-being, and they can all interact with one another. Human biological and psychological factors come into play on a personal level, but ecological and global systems are also involved, as are economics and access to health care, which determine the social vulnerabilities to disease. Recently, our chief means of controlling infections--antibiotics and insecticides-- have themselves become a source of new, resistant microbes and disease carriers, and the growing number of people with malnutrition or depressed immune systems have helped select and disseminate these emerging organisms.

Environmental conditions, interacting with the biology of disease agents, can exert profound effects. Changes in how land is used affect the distribution of disease carriers, such as rodents or insects, while climate influences their range, and affects the timing and intensity of outbreaks. In this review we examine how our health is influenced by the interplay of social conditions, local environmental factors, and global changes. The discussion focuses primarily on the environment, for--given its scale and pace of change--this sometimes forgotten determinant seems destined to play an ever-increasing role in determining disease patterns in the future.

At any time and in any age, human health tends to follow trends in both social systems and the natural environment. In periods of relative stability--measured in the number and distribution of people, their use of natural resources, and their generation of wastes--natural, biological controls over pests and disease organisms (or *pathogens*) can function efficiently. In times of accelerated change--often associated with economic or political instability, natural disasters, or war--infectious diseases can spread. Today, an increasingly unstable climate, the accelerating loss of species, and growing economic inequities challenge the resilience and resistance of natural systems. Acting together, these elements of change are contributing to the emergence, resurgence, and redistribution of infectious disease on a global scale (Fig. 1).

An expected redistribution of infectious disease is but one of the biological consequences of global environmental change. In some regions of the globe, warming may at first appear beneficial. Plants may be fertilized by warmth and moisture, an earlier spring, and more carbon dioxide (CO_2) and nitrogen. But warming and increased CO_2 can also stimulate microbes and their carriers, and added heat can destabilize weather patterns.

The consequences for agricultural pests and crop yields, for the health of livestock and fisheries, and for human illness may be significant; and the costs of epidemics can cascade through economies and ripple through societies. The resurgence of infectious diseases thus poses threats to food and biological security, and to economic development.

Water, food, and health are among our most basic needs. These requirements are also interrelated, and environmental changes now underway threaten all three. Maintaining health demands clean water, safe food, and unpolluted air, and in the modern world the latter depends upon clean energy. In the past, widespread diseases that affect multiple continents, called *pandemics*, have often precipitated social disruption and major shifts in human settlements. In other, more productive instances, the resurgence of infectious disease has inspired social and environmental reforms that addressed the underlying causes. What will be our course this time?

Background

A recent report of the United Nations' World Health Organization records that, since 1976, thirty diseases have emerged that are new to medicine. The reappearance of old diseases--once thought under control--is of equal concern: Drug-resistant **tuberculosis**, exacerbated by **HIV/AIDS**, now causes three million deaths annually, while childhood **diphtheria**, **whooping cough**, and **measles**--which are also transmitted person- to-person--are also on the rise, particularly in those places where social systems have recently changed. **Malaria**, **dengue** (or "breakbone fever," a severe, sometimes-deadly tropical disease transmitted by mosquitoes and accompanied by headache, rash, and severe joint pain), **yellow fever**, **cholera**, and a number of rodent-borne **viruses** are also appearing with increased frequency. The distribution of the latter diseases, that rely on animals or water as vehicles (or vectors) for transmission (Figure 2), reflect both environmental and social change. In 1995, U.S. mortality from infectious disease attributed to causes other than HIV/AIDS rose 22 percent above the levels of fifteen years before, and 58 percent in all.

Malaria as an example

Malaria is an ancient, mosquito-borne disease that played a significant role in the history of Africa. For centuries, the presence of sickle cell and other types of red blood cell "anomalies" limited the impact of **malaria** on native Africans. The disease also served to ward off foreign colonizers, who lacked these evolved defenses, and helped deter deep penetration of the continent until the latter part of the 19th century. In the first phases of the scramble for African territory, Europeans selectively colonized highland regions to escape from swampy regions of malaria, or "bad air": a choice that also contributed to the separation of the races. For further protection, they drank water flavored with quinine--a natural remedy, derived from the bark of the cinchona tree, discovered in Peru in the 15th century. To make the tonic more palatable, they added gin.

Eventually, control measures in Africa and the Americas, where **malaria** was also found, included environmental improvements and the application of insecticides, and by the 1950s there were dramatic drops in the incidence of the disease, worldwide. It was not conquered, however, but only held at bay. By the late 1970s, dwindling investments in public health programs, growing insecticide-resistance, and prevalent environmental changes, such as forest clearing, contributed to a widespread resurgence. By the late 1980s large epidemics were once again the rule, often associated with warm, wet periods.

In the past five years, the worldwide incidence of **malaria** has quadrupled, influenced by changes in both land development and regional climate. In Brazil, satellite images depict a "fish bone" pattern where roads have opened the tropical forest to localized development. In these "edge" areas **malaria** has resurged. Temperature changes have also encouraged a redistribution of the disease: **Malaria** is now found in higher-elevations in central Africa and could threaten cities such as Nairobi, Kenya (at about 5000 ft., or the altitude of Denver, Colorado), as freezing levels have shifted higher in the mountains. In the summer of 1997, for example, **malaria** took the lives of hundreds of people in the Kenyan highlands, where populations had previously been unexposed.

The anopheles mosquitoes that can carry **malaria** are present in the U.S., and, earlier this century, the disease was prevalent. After initially coming under control, small outbreaks of locally-transmitted **malaria** have occurred in this decade in Texas, Georgia, Florida, Michigan, New Jersey, and New York--and again, as in the 1980s, in California--primarily during hot, wet spells. A persistence of similar climatic conditions, combined with inadequate (or ineffective) control methods, could lead to further localized outbreaks.

Worldwide, up to 500 million people--roughly twice the present population of the U.S.--contract **malaria** every year, and between 1.5 and 3 million, primarily children, die. Africa is most affected. Mosquito resistance to insecticides and parasite resistance to many drugs are widespread, and there are no operational vaccines, nor any foreseen in the near future. Ecological changes, along with increased weather variability and a warming trend, appear to be playing increasing roles in the spread of this disease.

Environmental Change And Opportunistic Species

Regulatory mechanisms are a feature of all living systems. Some cells within the body stand guard to repel invading organisms, or to reject cells that develop malignantly. In the environment, predators serve a similar role, keeping populations of pests under control.

Weeds, rodents, insects, and microorganisms are opportunists that reproduce very rapidly. Rodents, for example, have huge broods, plus small body sizes, wide-ranging appetites, and well developed dispersal mechanisms.

In stable environments, large predators fare well and keep smaller, opportunistic species in check. But opportunists can readily colonize overly-stressed environments, much as opportunistic infections take hold in patients with weakened immune systems.

Mosquito populations, for example, are naturally controlled by reptiles, birds, spiders, ladybugs, and bats--as well as by pond fish that feed on mosquito larvae. Mosquitoes provide nourishment for these animals, but some carry **malaria**, **yellow fever**, **dengue fever**, and several types of **encephalitis**. Similarly, owls, coyotes, and snakes eat rodents; and rodents can devour grains and transport **Lyme disease** ticks, **hantaviruses** (a debilitating viral infection), **arenaviruses** (such as **South American hemorrhagic fevers** and **Lassa fever**), **leptospirosis** bacteria, and human **plague**.

In the marine environment, fish, shellfish, and sea mammals consume algae that form the base of the marine food web. A reduction in these plankton feeders as a result of overfishing or disease may thus contribute to blooms of harmful algae. Harmful algal blooms, or "HABs," that despoil beaches and devastate shoreline birds and other animal life, can occur as oxygen-rich "red tides," or as oxygen-poor or hypoxic "brown tides." Plankton blooms can also harbor **cholera** and other bacteria, and threaten the health of swimmers, or those who consume affected fish and shellfish.

Environmental change and biological controls

Today the activities of one species, humans, are reducing the diversity of all others and transforming the global environment. Ecosystems subjected to the stresses of "global change" (including climate change and altered weather patterns, the depletion of stratospheric ozone, deforestation, coastal pollution, and marked reductions of biological diversity) become more susceptible to the emergence, invasion, and spread of opportunistic species. When subject to multiple stresses, natural environments can exhibit symptoms that indicate reductions in resilience, resistance, and regenerative capabilities. Conversely, ecosystems have inherent flexibilities and survival strategies that can be strengthened by systematic stress, such as the seasonal battering they must endure in temperate latitudes. But their tolerance for abuse has its limits.

Several features of global change tend to reduce predators disproportionately, and in the process release prey from their biological controls. Among the most widespread are:

- Fragmentation and loss of habitat

- Dominance of monocultures in agriculture and aquaculture
- Excessive use of toxic chemicals
- Increased ultraviolet radiation, and
- Climate change and weather instability.

The breaking up of large tracts of forest or other natural wilderness into smaller and more diverse patches reduces the available habitat for large predators, and favors many pests. Land and climate changes may act synergistically, as when constricted habitat frustrates a species' ability to migrate north or south to survive altered climatic conditions. Extensive deforestation and climate anomalies--such as the delayed monsoon rains that resulted from this year's El Niño--can also act synergistically, with costly results. A ready example is the massive haze from burning that covered much of Southeast Asia in September and October, causing acute and chronic respiratory damage and losses in trade, investment, and tourism--the latter, a $26 billion a year industry.

The dedication of land to *monoculture*, that is, the cultivation of single crops with restricted genetic and species diversity, renders plants more vulnerable to disease. Simplified systems are also more susceptible to climatic extremes and to outbreaks of pests.

Over-use of pesticides kills birds and beneficial insects, as noted in 1962 by Rachel Carson. The title of her book, Silent Spring, made reference to the absence of the chorus of birds in springtime, and the resulting resurgence of plant-eating insects--that had also evolved a resistance to pesticides. The worldwide response to her message transformed agricultural policies and generated more enlightened pest management. But today, the heavy application of pesticides still carries risks to both human health and natural systems. Over-use of pesticides in Texas and Alabama to control the boll weevil has alarmed farmers, for friendly insects such as spiders and lady bugs have died off and other plant pests have rebounded.

Ecosystem Health

As noted earlier, one of "nature's services" is to keep opportunistic species under control. Maintaining this service entails sustaining the health and integrity of ecosystems. One of the essentials is genetic and species biodiversity to provide alternative hosts for disease organisms. Another is sufficient stability among functional groups of species (such as recyclers, scavengers, predators, competitors, and prey) to ensure the suppression of opportunists and preserve essential ecological functions. Habitat is crucial.

Stands of trees interspersed with agricultural fields, for instance, support birds that control insects; clean ponds with healthy populations of fish serve to control mosquito larvae; and adequate wetlands filter excess nutrients, harmful chemicals, and microorganisms.

As a case in point, in tidewater Maryland, buffer zones around farms and the restoration of wetlands and river-bed trees can absorb the flow of sediments, chemicals, and harmful organisms into Chesapeake Bay, and thus reduce the emergence and spread of algae, toxic to fish. Ecosystems are also interrelated: healthy forests and mangroves in Central America, for example, are crucial to coral reefs that spawn fish stocks, formed at the origin of the great Gulf Stream. Maintaining the integrity of natural environmental systems provides generalized defenses against the proliferation of opportunistic pests and disease.

Population explosions of nuisance organisms, be they animals or plants or microbes, often reflect failing ecosystem health: a sign of systems out of equilibrium, in terms of the balance of organisms required to perform essential functions. The damage done, moreover, can be cumulative, for multiply-stressed systems are less able to resist and rebound when other stresses come along.

Rodents, insects, and algae are thus key biological indicators of ecosystem health. Their populations and species compositions respond rapidly to environmental change--particularly to an increase in their food supply, or a drop in the number of their natural predators. These indicator species are also linked to human health.

Impacts of a loss of biodiversity

The present rate of species extinctions around the world is a potential threat to human health when one considers the role that predators play in containing infectious disease. From the largest to the smallest scales, an essential element in natural systems for countering stress is a diversity of defenses and responses. Thus, animals that seem redundant may serve as "insurance" species in a natural ecosystem, providing a back-up layer of resilience and resistance when others are lost from disease, a changing environment, or a shortage of food or water.

In 1996 the World Conservation Union reported that one-fourth of all species of mammals--and similar proportions of reptiles, amphibians, and fish--are threatened. The current rate of extinctions (estimated at 100 to 1,000 times the rate of loss in the pre-human era) falls heaviest on large predators and "specialists," and thus may initially favor the spread of opportunistic species.

Environmental Distress Syndome: Monitoring Global Change

Some ecologists describe an evolving "Environmental Distress Syndrome," with several recognizable symptoms that integrate local and global stresses. Such signals include the rapid decline (and widespread malformations) in frogs in 140 countries on six continents, which may be the result of habitat loss, toxic chemicals, and increased ultraviolet-B radiation. Additional and more general symptoms of environmental distress are given in the adjoining box.

An Environmental Distress Syndrome

1. Emerging infectious diseases.
2. The loss of genetic and functional group species biodiversity.
3. Among animals, and birds as a particular example, a growing dominance of "generalists" that have wide-ranging diets (such as crows, Canada geese, and gulls) over "specialists" (like plovers) whose localized niches are disappearing.
4. A pronounced decline in one type of specialist--the pollinators (such as bees, birds, bats, butterflies, and beetles)--whose activities are indispensable for the preservation of flowering plants, including crops.
5. Along coastlines, the proliferation of harmful algal blooms.

Monitoring these biological signs--as well as the populations of key biological indicator species such as rodents, insects, and algae--can strengthen observing systems that currently track chiefly chemical and physical parameters, such as nitrogen flow into coastal waters and sea surface temperatures. Interactive geographical mapping that visually integrates the biological, chemical, and physical measurements can help define and analyze the consequences, costs, and the causes of global environmental change.

Climate And Emerging Diseases

Models of how the climate system will respond to enhanced greenhouse warming predict (1) increased air temperatures at altitudes of two to four miles above the surface in the Southern Hemisphere; (2) a disproportionate rise in minimum temperatures (TMINs), in either daily or seasonally-averaged readings; and (3) an increase in extreme weather events, such as droughts and sudden heavy rains. There is growing evidence for all three of these tell-tale "fingerprints" of enhanced greenhouse warming, and each of them is related to infectious diseases.

Persistent hot, humid weather spells can threaten the health of people who live in temperate latitudes. Farm animals are also adversely affected, especially when the air temperature remains uncommonly high throughout the night.

During the summer of 1995, excess deaths in Chicago and other large cities around the world were directly associated with heat waves, compounded by social isolation. In many instances, according to meteorologists, the key factor was the lack of relief at night. In the latter half of this century, TMINs over land areas have risen at a rate of 1.86°C per 100 years, while maximum temperatures have risen at 0.88°C per 100 years. Mild conditions and recurrent winter thawing can also damage forests and can allow harmful insects to survive.

Warmer temperatures and vector-borne disease

Changing social conditions, such as the growth of "mega-cities," and widespread ecological change, are contributing to the spread of infectious diseases. But climate restricts the range in which *vector-borne diseases* ;nbsp(VBDs) can occur, and weather affects the timing and intensity of their outbreaks. Rates of insect biting and the maturation of microorganisms within them are temperature-dependent, and both rates increase when the air warms. Warming can also increase the number of insects, provided adequate moisture, although excessive heat can decrease survival of either microorganisms or their hosts. Between the limits of too hot and too cold is an optimum range of temperature in which warmer air enhances metabolism and the chances for disease transmission.

Most insects are highly sensitive to temperature change: ants even run faster in warmer weather. Findings from paleoclimatic (fossil) studies demonstrate that changes in temperature (and especially in TMINs) were closely correlated with geographic shifts of beetles near the end of the last Ice Age, about 10,000 years ago. Indeed, fossil records indicate that when changes in climate occur, insects shift their range far more rapidly than do grasses, shrubs, and forests, and move to more favorable latitudes and elevations hundreds of years before larger animals do. "Beetles," concluded one climatologist, "are better paleo-thermometers than bears."

Computer models of global greenhouse warming project increased temperatures that will, in turn, favor the spread of VBDs to higher elevations and to more temperate latitudes. While 42 percent of the globe presently offers conditions that can sustain the transmission of **malaria**, the fraction could rise to 60 percent with a global increase of a few degrees C (Fig. 3).

Mosquitoes are hot weather insects that have fixed thresholds for survival. Anopheline mosquitoes and **falciparum malaria** transmission are sustained only where the winter temperature is kept above 16°C (61°F), while the variety of mosquito that transmits **dengue fever**, Aedes aegypti, is limited by the 10°C (50°F) winter isotherm. Shifts in the geographic limits of equal temperature (*isotherms*) that accompany global warming may extend the areas that are capable of sustaining the transmission of these and other diseases. The transmission season may also be extended in regions that now lie on the margins of the temperature and moisture conditions that allow disease carriers to reproduce. Similar considerations apply to cold-blooded agricultural pests, called *stenotherms*, that require specific temperatures for their survival.

Some of these projected changes may already be underway, for, as summarized in the box below, there are now reports from several continents of new outbreaks of VBDs in mountainous regions-- findings that are consistent with the recorded temperature increase, the general retreat of alpine glaciers, and the reported upward displacement of temperature-sensitive plants.

Global Change In Montane Regions

Both insects and insect-borne diseases (including **malaria** and **dengue fever**) are today being reported at higher elevations in Africa, Asia, and Latin America. Highland **malaria** is becoming a problem for rural areas in Papua New Guinea and for the highlands of Central Africa. In 1995, **dengue fever** blanketed Latin America, and the disease or its mosquito vector, *Aedes aegypti*, are appearing at higher elevations. In addition, the displacement of plants to higher elevations has been documented on thirty peaks in the European Alps, and has also been observed in Alaska, the Sierra Nevada range in the U.S., and in New Zealand. These botanical trends, indicative of gradual, systematic warming, accompany other widespread physical changes: Montane glaciers are in retreat in Argentina, Peru, Alaska, Iceland, Norway, the Swiss Alps, Kenya, the Himalayas, Indonesia, and New Zealand. Some may soon disappear.

Since 1970 the lowest level at which freezing occurs has climbed about 160 meters higher in mountain ranges from 30°N to 30°S latitude, based on radiosonde data analyzed at NOAA's Environmental Research Laboratory. The shift to higher levels on mountainsides corresponds to a warming at these elevations of about 1°C (almost 2°F), which is nearly twice the average warming that has been documented over the Earth as a whole. Notably, atmospheric models that incorporate observed trends in stratospheric ozone, sulfate aerosols, and greenhouse gases predict that, at least in the Southern Hemisphere, the warming trend at high mountain elevations should exceed that at the Earth's surface. Thus, mountain regions--where shifts in isotherms are especially apparent--can serve as sentinel areas for monitoring global climate change.

The consistency among physical and biological indicators agrees with the most recent, 1996 consensus findings of the Intergovernmental Panel on Climate Change (IPCC) that climate appears to be changing, and that some of the anticipated impacts are now observable. The IPCC also concluded that human activities, including fossil fuel combustion and forest clearing and burning, are apparently contributing to these changes. There may be some positive impacts such as fewer winter deaths, or a drop in **schistosomiasis** in areas where excessive heat kills off the snails that can carry the parasite larvae. But overall, the current evaluation is that the impacts of an unstable and rapidly changing climate on human health are likely to be overwhelmingly negative.

The Effects Of Climate Variability On Epidemics

Another significant climate trend that has been linked to systematic changes in temperature and precipitation is an increase in the variability, or extremes, of climate. This change in extremes can alter not only the intensity of individual events, such as storms and floods, but the timing and spatial patterns of weather as well. Since the mid-1800s the average surface temperature of the globe has risen about 0.4°C-0.6°C, and periods of persistent warming can, in general, be associated with increased variability. The IPCC projects that the warming trend may be accompanied by more intense heat waves and altered drought and rainfall patterns.

As reported in the first issue of CONSEQUENCES, data from the National Climatic Data Center--this nation's main repository for meteorological data--indicate that, since the 1970s, extreme weather events have indeed increased in the continental U.S. On average, periods of drought are systematically longer, and bursts of precipitation (greater than two inches of rain over twenty- four hours) are more frequent. A warmed atmosphere accelerates evaporation, and for every rise of 1°C, the air can hold 6 percent more water. One consequence is that we are now receiving a greater percentage of precipitation in the form of sudden, intense bursts that are more typical, for example, in the tropics. Longer droughts and more heavy bursts of rain, accompanied by flash floods, were more common in the 1980s than in the 1970s, and more so in the 1990s than in the 1980s.

Extreme events--floods, storms, droughts, and uncontained fires--can be devastating for agriculture, for human settlements, and for health. More, brief cold snaps are also possible, and winter storms, like heat waves, bring an increase in **cardiac deaths**. Floods spread bacteria, viruses, and chemical contaminants, foster the growth of fungi, and contribute to the breeding of insects. Prolonged droughts, interrupted by heavy rains, favor population explosions of both insects and rodents. Extreme weather events (often associated with the recurring climatic conditions that are initiated by large-scale changes in sea surface temperatures in the Pacific, known as El Niño/La Niña events) have been accompanied by new appearances of harmful algal blooms in Asia and North America, and--in Latin America and Asia--by outbreaks of **malaria** and various water-borne diseases, such as **typhoid**, **hepatitis A**, **bacillary dysentery**, and **cholera**.

Disease Clusters

In August 1995 the eastern, tropical region of the Pacific Ocean surface turned cold, initiating a La Niña event that would last until late 1996. Along the Caribbean coast of Colombia a summer 1995 heat wave was followed by the heaviest August rainfall in fifty years, ending a long drought that accompanied the preceding, prolonged El Niño conditions of 1990-1995. The heat and flooding precipitated a cluster of diseases involving mosquitoes (Venezuelan **equine encephalitis** and **dengue fever**), rodents (**leptospirosis**), and toxic algae (that killed 350 tons of fish in their largest coastal lagoon).

Prolonged anomalous conditions of the sort that applied in 1990- 1995 can also have cumulative biological consequences. In New Orleans, for example, five years without a killing frost was associated with an explosion of mosquitoes, termites, and cockroaches. Termites persisted inside trees into the cold winter of 1995-1996, and now threaten to destroy stands of New Orleans' fabled "mighty oaks." We may have only just begun to understand the true biological impacts of the persistent anomalous climate of the 1990s.

Rodents: Synergies And Surprises

Rodents are today a growing problem in the U.S., Latin America, Africa, Europe, Asia, and Australia. These preeminent opportunists are believed to be the fastest reproducing mammal and they eat everything humans do, thrive on contaminated water and food, and are extremely capable swimmers. Meadow voles, whose numbers are kept in check by predatory marsh hawks, can have up to seventeen broods a year, for example, each of half a dozen offspring. Rodents consume 20 percent of the world's grain, including almost a seventh in our own country, and up to three quarters of what is grown and stored in some African nations. Rodents can also carry diseases.

A controlled experiment with Canadian snowshoe hares depicts how multiple factors can act synergistically to greatly increase the number of rodents. Excluding predators by confining the rabbits to cages led to a population doubling, compared to the fate of a number of similar animals in the wild. Augmenting food tripled hare density. Together the interventions in the controlled experiment resulted in more than a ten-fold population explosion.

Rats, mice, and the hantavirus

The story of the **hantavirus** illustrates a similar synergy in the case of microbial agents.

A prolonged drought in the U.S. southwest in the early 1990s reduced the populations of animals such as owls, coyotes, and snakes that prey on rodents. When the drought yielded to intense rains in 1993, the grasshoppers and piñon nuts on which rodents feed became more abundant. The result, when combined with the drop in predators, was a ten-fold increase in rats and mice by June of that year. An outcome was the emergence of a "new" disease called **Hantavirus Pulmonary Syndrome**: from a virus--perhaps already present, but dormant--transmitted through rodent saliva, urine, and droppings. Predators returned, however, and by summer's end the outbreak had abated.

Rodent-borne **hantaviruses** have resurged in several European nations, and most notably in the former Soviet Union and in Yugoslavia. In late 1996, **hantavirus** infection emerged in South America in western Argentina. Within the first few months at least ten deaths resulted, frightening off tourists and threatening the economic livelihood of the region. **Hantavirus Pulmonary Syndrome** has now appeared in Bolivia, Brazil, Canada, Chile, Ecuador, Paraguay, and Uruguay, with about 50 percent mortality and several cases of person-to-person transmission.

Some other examples

Evidence of another rodent-borne disease --**leptospirosis**-- is increasingly reported in U.S. urban centers, in areas where the disposal of sewage and other measures to protect public health have declined. In 1995, there were substantial outbreaks of the disease in Central America and Colombia, as heavy (La Niña) rains, following the prolonged El Niño drought, drove rodents scurrying from their burrows. **Leptospirosis** is treatable with antibiotics; but there were fatalities in 1995 before the diagnosis was established.

A combination of stresses contributed to the sudden appearances of several rodent-borne **viral hemorrhagic fevers** in rural Latin America in the past several decades: **Junin** in Argentina (1953), **machupo** in Bolivia (1962 and 1996), **guaranito** in Venezuela, and **sabiá** in Brazil. In Bolivia, systematic clearing of trees apparently shifted populations of a variety of disease-carrying mice, known as calomys, from forest to field settings where they became dominant. Heavy applications of DDT --meant to eradicate **malaria**-- helped reduce their natural predators. When cats were reintroduced to the area in 1962, the epidemic of **Bolivian hemorrhagic fever** was abated, although not until it had killed 10 to 20 percent of the inhabitants of the small villages in which the disease was present. Habitat loss and excessive use of toxic chemicals acted together in this case.

In southern Africa, rodent populations exploded as a consequence of climate variability, when heavy and then lighter rains came in 1993 and 1994, on the heels of six years of prolonged drought. When the rains came, rodents found themselves in a world where avian and land predators were virtually absent. Moreover, because so many draft animals had also succumbed, there was little tillage of the land and the underground burrows in which rodents live went largely undisturbed. After an initial successful harvest in 1993, the maize crop in Zimbabwe was decimated by rodents. Soon after, human **plague** broke out in Zimbabwe and on the borders of neighboring Malawi and Mozambique, carried--as in the devastating plague of 14th century Europe--by fleas on rats. Subsequently, a rodent-borne virus took the lives of eighty-one elephants in South Africa's Kruger Park, and plague returned in the summer of 1997.

Plague in India resurfaced in 1994, following a blistering summer when temperatures reached 124°F, leaving animals prostrate in the northern part of the country and fueling the breeding of fleas in houses that held stored grain. The unusually heavy monsoons following the 1994 heat wave led to population crowding in Surat on the western coast, north of Bombay, and an apparent outbreak of **pneumonic** (person-to-person) **plague**. Cases of **malaria** and **dengue fever** also surged in the wake of flooding. Meanwhile, in Australia, rodents emerged as serious crop pests in 1995, accompanying the same prolonged El Niño of the early 1990s and the ensuing years of intense drought.

Current land-use practices and the overuse of chemicals to control pests may increase the chances for such "nasty synergies." Climate variability is also a key element in upsurges of pests--and were climate to become more unstable, it could exert an even greater influence on ecological dynamics and the patterns of infectious diseases in the future. A disturbance in one factor can be destabilizing; but multiple perturbations can reduce the resistance and the resilience of a entire system.

Marine Coastal Ecosystems

Seashores throughout the world are subject to increasing pressures from residential, recreational, and commercial development. These stresses may become more severe, for human population in the vicinity of sea-coasts is growing at twice the inland rate. Some of the pressures that we exert on coastal ecosystems are summarized in the accompanying box. All can increase the growth of algae.

Marine Ecosystem Stresses

1. An excess in coastal waters of dissolved mineral and organic nutrients, particularly from nitrogen overload--derived from sewage, agricultural fertilizers, and acid precipitation-- resulting in an environment that favors plant over animal life.
2. Reduced acreage of wetlands, that serve as "nature's kidneys" to filter nitrogen and other wastes that flow from the coastal environment.
3. Overfishing, that can reduce the population of beneficial predators of algae and animal plankton (zooplankton).
4. Chemical pollution and increased penetration of UV-B radiation that may increase mutation levels in near-shore sea life of all kinds, and disproportionately harm zooplankton and fish larvae.
5. Warming of coastal waters--and the associated trend toward stable, thermal layers that inhibit vertical circulation--which increases the metabolism and growth of algae, and favors more **toxic algal species** such as cyanobacteria and dinoflagellates. Warming may also reduce the immune systems of sea mammals and coral, and encourage the growth of harmful bacteria and **viruses** in their tissues.

Among the possible consequences of disruption in almost any marine ecosystem is an increase in the opportunistic pathogens that can abet the spread of human disease, sometimes to widespread proportions. One example is **cholera**.

Cholera

We often think of our modern world as cleansed of the epidemic scourges of ages past. But **cholera** --an acute and sometimes fatal disease that is accompanied by severe diarrhea-- affects more nations today than ever before. The Seventh Pandemic began when the El Tor strain left its traditional home in the Bay of Bengal in the 1960s, traveled to the east and west across Asia, and in the 1970s penetrated the continent of Africa. In 1991, the **cholera** pandemic reached the Americas, and during the first eighteen months more than half a million cases were reported in Latin America, with 5,000 deaths. Rapid institution of oral rehydration treatment--with clean water, sugar, and salts--limited fatalities in the Americas to about one in a hundred cases. The epidemics also had serious economic consequences. In 1991, Peru lost $770 million in seafood exports and another $250 million in lost tourist revenues because of the disease.

The microbe that transmits **cholera**, Vibrio cholerae, is found in a dormant or "hibernating" state in algae and microscopic animal plankton, where it can be identified using modern microbiological techniques. But once introduced to people--by drinking contaminated water or eating contaminated fish or shellfish-- **cholera** can recycle through a population, when sewage is allowed to mix with the clean water supply.

Five years ago, in late 1992, a new strain of Vibrio cholerae--O139 Bengal--emerged in India along the coast of the Bay of Bengal. With populations unprotected by prior immunities, this hardy strain quickly spread through adjoining nations, threatening to become the agent of the world's Eighth Cholera Pandemic. For a time, in 1994, El Tor regained dominance. But by 1996, O139 Bengal had reasserted itself. The emergence of this new disease, like all others, involved the interplay of microbial, human host, and environmental factors.

The largest and most intense outbreak of **cholera** ever recorded occurred in Rwanda in 1994, killing over 40,000 people in the space of weeks, in a nation already ravaged by civil war and ethnic strife. The tragedy of **cholera** in Rwanda is a reminder of the impacts of conflict and political instability on public health and biological security--just as epidemics may, in turn, contribute to political and economic stability.

Is The Ocean Warming?

Surface temperatures of the ocean have warmed this century, and a gradual warming of the deep ocean has been found in recent years in oceanographic surveys carried out in the tropical Pacific, Atlantic, and Indian Oceans, and at both poles of the Earth. These findings could be indicative of a long-term trend. Corresponding temperature measurements of the sub-surface earth, in cores drilled deep into the Arctic tundra, show a similar effect.

The water that evaporates from warmer seas, and from vegetation and soils of a warmer land surface, intensifies the rate at which water cycles from ocean to clouds and back again. In so doing it increases humidity and reinforces the greenhouse effect. Warm seas are the engines that drive tropical storms and fuel the intensity of hurricanes. More high clouds can also contribute to warmer nights by trapping out-going radiation.

Some biological impacts

A warmer ocean can also harm marine plankton, and thus affect more advanced forms of life in the sea. A northward shift in marine flora and fauna along the California coast that has been underway since the 1930s has been associated with the long-term warming of the ocean over that span of time.

Warming--when sufficient nutrients are present--may also be contributing to the proliferation of coastal algal blooms. Harmful algal blooms of increasing extent, duration, and intensity--and involving novel, toxic species--have been reported around the world since the 1970s. Indeed, some scientists feel that the worldwide increase in coastal algal blooms may be one of the first biological signs of global environmental change.

Warm years may result in a confluence of adverse events. The 1987 El Niño was associated with the spread and new growth of tropical and temperate species of algae in higher northern and southern latitudes. Many were toxic algal blooms. In 1987, following a shoreward intrusion of Gulf Stream eddies, the dinoflagellate Gymnodimuim breve, previously found only as far north as the Gulf of Mexico, bloomed about 700 miles north, off Cape Hatteras, North Carolina, where it has since persisted, albeit at low levels. Forty-eight cases of **neurological shellfish poisoning** occurred in 1987, resulting in an estimated $25 million loss to the seafood industry and the local community. In the same year, anomalous rain patterns and warm Gulf Stream eddies swept unusually close to Prince Edward Island in the Gulf of St. Lawrence. The result, combined with the run-off of local pollutants after heavy rains, was a bloom of toxic diatoms. For the first time, domoic acid was produced from these algae, and then ingested by marine life. Consumption of contaminated mussels resulted in 107 instances of **amnesic shellfish poisoning**, from domoic acid, including three deaths and permanent, short-term memory loss in several victims.

Also in 1987, there were major losses of sea urchin and coral communities in the Caribbean, a massive sea grass die-off near the Florida Keys, and on the beaches of the North Atlantic coast, the death of numerous dolphins and other sea mammals. It has been proposed that the combination of algal toxins, chlorinated hydrocarbons like PCBs, and warming may have lowered the immunity of organisms and altered the food supply for various forms of sea life, allowing *morbilli* (measles-like) **viruses** to take hold.

The 1990s

For five years and eight months, from 1990 to 1995, the Pacific Ocean persisted in the warm El Niño phase, which was most unusual, for since 1877 none of these distinctive warmings had lasted more than three years. Both anomalous phases-- with either warmer (El Niño) or colder (La Niña) surface waters-- bring climate extremes to many regions across the globe. With the ensuing cold (La Niña) phase of 1995-1996, many regions of the world that had lived with drought during the El Niño years were now besieged with intense rains and flooding. Just as in Colombia, flooding in southern Africa was accompanied by an upsurge of vector-borne diseases, including **malaria**. Other areas experienced a climatic switch of the opposite kind, with drought and wildfires replacing floods. During 1996 world grain stores fell to their lowest level since the 1930s.

Weather always varies; but increased variability and rapid temperature fluctuations may be a chief characteristic of our changing climate system. And increased variability and weather volatility can have significant consequences for health and for society.

Decadal variability

The cumulative meteorological and ecological impacts of the prolonged El Niño of the early 1990s have yet to be fully evaluated, and another is now upon us. In 1995, warming in the Caribbean produced coral bleaching for the first time in Belize, as sea surface temperatures surpassed the 29°C (84°F) threshold that may damage the animal and plant tissues that make up a coral reef. In 1997, Caribbean sea surface temperatures reached 34°C (93°F) off southern Belize, and coral bleaching was accompanied by large mortalities in starfish and other sea life. Coral diseases are now sweeping through the Caribbean, and diseases that perturb marine habitat, such as coral or sea grasses, can also affect the fish stocks for which these areas serve as nurseries.

A pattern of greater weather variability has begun and is expected to persist with the El Niño of 1997 and 1998. Since 1976, such anomalies in Pacific Ocean temperatures and in weather extreme events have become more frequent, more intense, and longer lasting than in the preceding 100 years, as indicated in records kept since 1877.

Discontinuities And Instabiliby

The common perception that the natural world changes only gradually can be misleading, for discontinuities abound. Animals switch abruptly between two states--awake and asleep--that are sharply divided and marked by qualitative differences in levels of activity in the central nervous system. Water can rapidly change from vapor to liquid to solid. Ecosystems have equilibrium states that are also at times abruptly interrupted. An extensive fire in an old growth forest, for example, can radically change the types of plants and animals within it.

Climate regimes can also change surprisingly fast. Recent analyses of Greenland ice cores indicate that significant shifts, called rapid climate change events (RCCEs), have taken place in the past in the span of but several years--not centuries, as was previously believed. While the oceans may serve as a buffer against sudden climate change, this mechanism may be limited, for some of the RCCEs seem to be associated with abrupt changes in ocean circulation.

The climate system exhibits equilibrium states as well, of which three may have been most common: when the poles of the Earth were covered with small, medium, or large ice caps. The present, Holocene period of the last 10,000 years--with medium-size caps and an average global temperature of 15°C (about 60°F)-- has been associated with the development of modern agriculture and advancing civilization. But our present climate regime may be becoming less stable. Increased variance--that is, more extreme swings--in natural systems is inversely related to how stable and balanced the systems are, and how sensitive they are to perturbations. Wider and wider variations can occur as a system moves away from its equilibrium state.

Trends in the 20th century

The gradual warming that characterized the climate during the first four decades of the present century, for example, was accompanied by substantial temperature variability, as borne out in the record of degree-heating-days in the U.S. grain belt. The ensuing cooling trend from 1940 to the mid 1970s showed less variability. From 1976 to the present day, the variability--apparent in hot and cold spells, drought, and floods--has again increased. Greenland ice core records suggest that the last time the Earth warmed abruptly, ending the last Ice Age, there was also a pattern of increased variability.

The connection between human health and environmental stability increases our need for a better understanding of the present state of the global climate system. There are several unanswered questions regarding the system's stability. Was the drift toward earlier springtimes that began in this country in the 1940s indicative of the first minor readjustment in the climate regime? Are the more frequent and intense El Niño events since the mid 1970s another such indicator? Has the baseline of ocean temperatures shifted? Does the present climatic volatility--evident in altered weather and precipitation patterns--increase the potential for an abrupt "jump" in the climate system? And might further stresses lead to abrupt discontinuities of the type found in the Greenland ice cores, when the last Ice Age rapidly came to an end?

The Costs Of Climate Variability And Disease Outbreaks

Regardless of what caused it, the recent rise in severe wind and flood-related events worldwide has had extraordinary consequences for property insurers. Prior to 1989, no single-event insured loss in the U.S. had ever exceeded a billion dollars. Since then, annual insured losses have risen dramatically--from almost $1.6 billion annually in the 1980s to $10 billion in the 1990s: a jump that is only partially explained by more intensive exploitation of rivers and land and seashore property. Federal relief bills, chiefly from flooding, totaled $13 billion for the last five years, compared to $3.3 billion for the preceding five.

Because they combine exposure with weather-related events, the costs to the property insurance industry may be the most telling indicator of the non-sustainability of our interference with natural global systems. With continued extreme climate variability, health and environmental restoration costs may grow in a similar manner. It is significant that we are having difficulty insuring our future.

The economic impacts of disease in humans, livestock, and food crops can also be severe and far-reaching. Today the white fly--whose numbers swell when there is drought--is injecting at least eighteen types of **geminiviruses** into tomato, squash, and bean plants throughout Latin America, depleting the primary source of protein for many who live there. Recently a **necrosis virus** (vectored by soil-based fungi) that attacks rice has appeared in Colombia. Further spread of a disease of this staple food source could have enormous impacts on world food supplies.

While the 1991 **cholera** epidemic cost Peru over $1 billion in tourist income locally, international airline and hotel industries lost from $2 to $5 billion from the 1994 Indian plague. Cruise boats, quite understandably, have begun to avoid islands racked by **dengue fever**. In the Caribbean, this trend could threaten a $12 billion-a-year tourist industry that employs more than half a million people. The 1997 California floods left fungi and root rot that threatens that state's $22 billion citrus industry. Indeed, the global resurgence of **malaria**, **dengue fever**, and **cholera**, and the emergence of relatively new diseases like **Ebola**, **toxic Escherichia coli** and **Mad Cow disease** --which are related to ecology and animal husbandry practices-- affect not only the health of individuals but also of national economies.

An Historical Notes On Pandemics

Pandemics emerge out of social and environmental conditions, and they can induce changes in both of them. At times the resulting changes have been disruptive; in other instances they have stimulated significant social reform.

The rise and fall of infectious disease

From a long-term historical perspective, pandemics have often been associated with major social transitions and overtaxed infrastructure. Their impacts have been lasting and profound.

A pandemic, of debated cause but remembered as the **Plague of Justinian**, struck Europe in A. D. 541. It came as the Roman Empire was in decline, and it raged for two centuries, claiming over 40 million lives, in an era when the total population of the Earth was at most 300 million. Urban centers were abandoned and the **plague** helped drive population resettlement into rural, feudal communities before it disappeared.

After a 600-year hiatus, **plague** again appeared, in A.D. 1346--at the depths of the Middle Ages--when growing urban populations had again outstripped the capabilities of cities to sustain sanitation and basic public health. Several other factors played compounding roles: Human populations had migrated from East to West; the Medieval Warm Period of the 12th and 13th centuries may have contributed to the proliferation of rats and fleas that carried the so-called **bubonic plague**; and cats had been killed in the belief that they were witches. In the ensuing five years of the so- called "Black Death," about 25 million lives were taken--about one of every three persons who lived in Europe at the time. Social relations and labor patterns were dramatically altered throughout Europe.

A third outbreak of widespread epidemic disease, almost 300 years later, had a more positive outcome.

In the course of the early Industrial Revolution, improvements that accompanied development led to a substantial decline in mortality from infectious disease. Then, in the 1830s, under the burgeoning weight of industrialization and the growth of population--seven-fold in London from 1790 to 1850--the conditions in European cities described in the novels of Charles Dickens became breeding grounds for three major infectious diseases: **cholera**, **smallpox**, and **tuberculosis**. Suddenly growth and development had outgrown infrastructure, and infectious diseases rebounded.

But the resurgence of infectious disease this time precipitated protests throughout the European continent, and ultimately led to constructive responses. In England, the Sanitary and Environmental Reform Movements were born; and the field of epidemiology ushered in modern public health principles and eventually, led to a national health program. The epidemics abated in the course of several decades (Fig. 4), three-quarters of a century before the advent of anti-microbials.

Recent history

By the 1960s widespread improvements in hygiene, sanitation, and mosquito control led most public health authorities to believe that we would soon conquer infectious diseases. In the 1970s public health schools turned their attention instead to chronic ailments, such as **heart disease**, **stroke**, **diabetes**, and **cancer**. But the so-called "epidemiological transition" to diseases of modernity never materialized in many developing nations. And, in the 1980s, the global picture shifted dramatically.

According to the U.N. World Health Organization's 1996 report, drug- resistant strains of bacteria and other microbes are having a deadly impact on the fight against several diseases, including **tuberculosis**, **malaria**, **cholera**, and **pneumonia** --which collectively killed more than 10 million people in 1995. Spread of resistant organisms resulted from antibiotic overuse, microbial mutations, and the geographic movement of humans, insects, rodents, and microbes. Ironically, our very means to control infectious disease--antibiotics and insecticides--are, themselves, rapidly driving the evolution of new and unaffected strains. Notably, two thirds of antibiotic use is in animal husbandry, agriculture, and aquaculture.

In the 1990s, **diphtheria** rose exponentially in the former USSR as the public health system deteriorated following political and economic changes. The incidence rose from 4000 cases in 1992, to 8000 in 1993, and 48,000 in 1994, claiming the lives of over 4000 residents since 1990. Incidence has risen in fifteen nations of Eastern Europe, although recent immunization campaigns have begun to control this infection.

Dengue fever, for which no vaccine is yet available, had essentially disappeared from the Americas by the 1970s, but has resurged in South America, infecting over 300,000 people in 1995-- which was, notably, the warmest year of this century. "Aedes aegypti is now well established in all areas of the Americas except Canada and Chile," ran a recent editorial in the British medical journal Lancet.

Settlements that surround typical mega-cities, where discarded non- biodegradable containers serve as ideal mosquito breeding sites, provide especially vulnerable settings; milder "cold" seasons and weather extremes can both help precipitate large outbreaks. Additionally, previous exposure and a change in the type of viral **dengue** circulating may lead to **Dengue hemorrhagic fever**, that carries a 5 to 10 percent mortality.

In 1995 the largest epidemic of **yellow fever** since 1950 -- carried by the same mosquito that transmits **dengue** --hit the Americas. Peru and the Amazon basin were heavily impacted, and there is a growing potential for urban **yellow fever**. While there is a **yellow fever** vaccine, the current supply may be inadequate for future needs.

Finally, in 1996 the largest epidemic ever recorded of **meningitis** struck West Africa, associated with pervasive drought, since dry mucus membranes may aid the invasion of the colonizing organisms. Over 100,000 persons contracted the disease and more than 10,000 people died. A vaccine is available, but must be used early to stop an epidemic.

Who is at risk?

Conditions conducive to the spread of epidemic infectious diseases now exist worldwide, according to the WHO report, and domestic environmental and social conditions that favor the spread of these diseases are present in the U.S. today. Infectious diseases that have emerged, like **Hantavirus Pulmonary Syndrome**, **Lyme Disease**, and **toxic E. coli** were not imported from other nations. **E. coli**, for example, spreads in cattle raised in close quarters.

The transmission of **tuberculosis**, another example, is facilitated in homeless shelters and in prisons. And while poorer populations are at greatest risk, outbreaks of infectious disease are not restricted to disadvantaged regions, for today's population movements facilitate "microbial traffic" between nations and economic groups.

What Can Be Done?

The concerns that have been elaborated here are not hopeless: there are solutions to all of them. The steps that are needed, moreover, would benefit our own and future generations regardless of the future course of climate or the inevitable environmental surprises that await us in years ahead. Solutions can be divided into three levels, ranging from tactical and immediate, to strategic and long- term, and all are within our present capabilities.

The first-level solution is improved surveillance and response capability for the public health sector, that includes the development of vaccines, better treatments, and more widespread support, around the world, for public health measures.

The second is the integration of health surveillance as an element of the kind of environmental monitoring that is called for in the accompanying article in this issue of CONSEQUENCES. We need to make greater use of remote sensing and climate forecasts--as for El Niño/La Niña occurrence--to develop health early warning systems to alert communities of conditions conducive to the outbreak of infectious diseases.

The third level is the evaluation of environmental and energy policies in the context of their impacts on human health and well- being. Maintaining the integrity of ecosystems, such as forest habitat and wetlands, can provide defense against outbreaks of the opportunists that carry disease, and provide a buffer against climatic vagaries and extremes, whether or not there is any change in the overall climate regime. Early interventions can save money and lives.

A Personal Conclusion

There are more and more fingerprints of an impending change in the global climate, and ever more evidence of our own ecological footprint on natural systems. We are living in a period of accelerated social, ecological, and climatic change. But will our global society react to the symptoms of environmental dysfunction in time to take corrective measures?

We are changing the chemistry of the air, and in the process altering the heat budget of the world. It is the multiple changes induced in the Earth's atmosphere--carbon buildup, sulfate accumulation, and ozone depletion--that constitute a destabilizing array of forcing factors. Together they may already have begun to alter natural climatic modes, such as the frequency and strength of the El Niño-Southern Oscillation. These modifications--along with the changes in coastal ocean chemistry--have begun to affect biological systems and human health.

Behind these chemical, physical, and biological changes is our ever- increasing use of the Earth's finite resources, and our generation of wastes at rates beyond which biogeochemical systems can adequately recycle them. These patterns of consumption are simply not sustainable and come at costs that are real, often very high, and not acknowledged by current systems of economic accounting. Practices affecting forestry, fisheries, petrochemicals, and fossil fuels need all be examined in light of their costs across the full range of their ultimate impacts, including their effects on biodiversity, climate, and the global resurgence of infectious diseases. Some of these practices now facilitate the spread of diseases by altering the environment, and others by undermining social infrastructures. The global environment is most drastically at risk from changes in the climate that are almost certain to follow our escalating combustion of fossil fuels. Air pollution--by particles and smog from fossil fuel combustion--add to the health hazards of warming. Ultimately, according to the first IPCC report, the world must reduce present greenhouse gas emissions from 60 to 70 percent to stabilize the concentrations in the atmosphere and, we can hope, allow natural systems to readjust. The U.N.-sponsored Framework Convention on Climate Change that addresses the burning of fossil fuels is an essential step, for the global carbon budget is key to all living systems.

The instability of many economies also jeopardizes the public health. Population growth and the relocation of people, driven by economic, environmental, and political factors, exert enormous pressures on the environment. Migration levels of the past two decades--within and between nations--surpass the great migrations of the 1800s. World Bank figures, not surprisingly, confirm that the ability of a society to stabilize its population--and as a consequence, bring public health and environmental degradation under control--is directly related to the degree of equity of income within it.

Unfortunately, international burdens of debt, binding austerity programs, unequal terms of trade, and numerous subsidies negate many of the policies, plans, and projects designed to alleviate poverty, preserve the environment, and stimulate economic growth and security. Short-term, microeconomic goals are hampered by stronger macroeconomic forces, creating social instability and ultimately retarding healthy development.

The global resurgence of infectious disease in the last quarter of the twentieth century--a backward step that few would have anticipated twenty years ago--is a clear consequence of combined and compounding changes in physical, chemical, biological, and social systems. Greater disease surveillance and response capability are the first, essential, steps. But viewed as a symptom, the resurgence of infectious disease across a wide taxonomic range may indicate that we may be vastly underestimating the true costs of "business-as- usual."

Fortunately, consciousness and values can change even more rapidly than do the natural systems we all depend upon. We face important decisions in the way we use and re-use the finite resources that are available to us. Perhaps we are also vastly underestimating the economic opportunities and employment benefits to society as a whole as we make the transition to use resources more efficiently, generate energy cleanly, and restore essential functions of the natural environment. Curbing our unhealthy addiction to fossil fuels may be the lever that opens the portal to a healthy and productive future.

Reviewers

Dr. Eric Barron, who serves on CONSEQUENCES' Scientific Editorial Board, is Director of the Earth System Science Center and Professor of Geosciences at the Pennsylvania State University in University Park. His interests are in ocean and atmosphere modeling and global environmental change, with an emphasis on both past and future climates.

Dr. Joel Breman, an M.D. with a Diploma in Tropical Public Health, is Deputy Director of the Division of International Training and Research at the Fogarty International Center of the National Institutes of Health in Bethesda, Maryland. His research interests are in the epidemiology and ecology of infectious diseases and the evaluation of control and eradication programs.

Dr. Gary L. Simpson, M.D., is the Medical Director for Infectious Diseases at the State Department of Health in Santa Fe, New Mexico. He also holds a Ph.D. in molecular biology and advanced degrees in clinical medicine and in tropical public health. Dr. Simpson has practiced medicine in Massachusetts and New Mexico and has served as a fellow or on the faculty of medicine at Harvard, Stanford, the University of New Mexico, the University of Oxford, and the National Institute of Health in Bogotá, Columbia.

Dr. Warren M. Washington, an atmospheric scientist, is a senior scientist and former Director of the Climate and Global Dynamics Division at the National Center for Atmospheric Research in Boulder, Colorado. He also serves on the Presidentially-appointed National Science Board. Dr. Washington's research interests are in climate modeling and in conducting computer simulations of climate change.

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