

# Climate Change Futures

## Health, Ecological and Economic Dimensions



A Project of:  
The Center for Health and the Global Environment  
Harvard Medical School

Sponsored by:  
Swiss Re  
United Nations Development Programme



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and the Global Environment  
Harvard Medical School

Swiss Re



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The full list of the Centre for Global Dialogue Executive Roundtable participants is appended.

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## PREAMBLE

What was once a worst-case scenario for the US Gulf Coast occurred in August 2005. Hurricane Katrina killed hundreds and sickened thousands, created one million displaced persons, and sent ripples throughout the global economy, exposing the vulnerabilities of all nations to climate extremes.

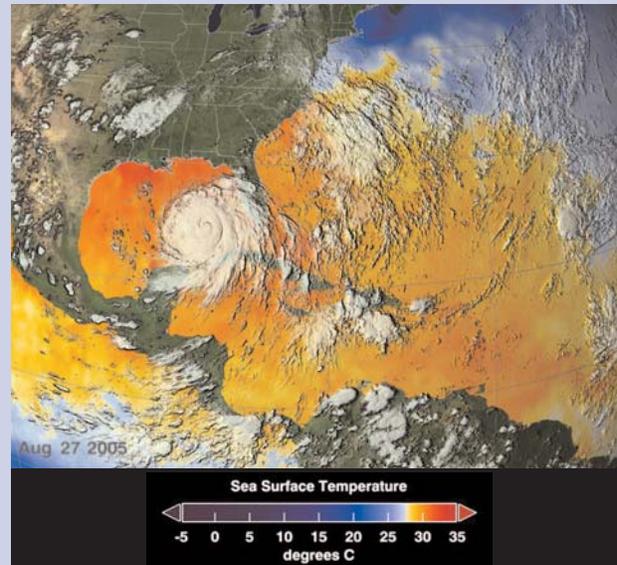
While no one event is conclusive evidence of climate change, the relentless pace of severe weather — prolonged droughts, intense heat waves, violent windstorms, more wildfires and more frequent “100-year” floods — is indicative of a changing climate. Although the associations among greater weather volatility, natural cycles and climate change are debated, the rise in mega-catastrophes and prolonged widespread heat waves is, at the very least, a harbinger of what we can expect in a changing and unstable climate.

For the insurance sector, climate change threatens the Life & Health and Property & Casualty businesses, as well as the health of insurers’ investments. Managing and transferring risks are the first responses of the insurance industry — and rising insurance premiums and exclusions are already making front-page news. Many corporations are changing practices and some are seizing business opportunities for products aimed at reducing risks. Corporations and institutional investors have begun to consider public policies needed to encourage investments in clean energy on a scale commensurate with the heightened climate and energy crises.

The scientific findings underlying the unexpected pace and magnitude of climate change demonstrate that greenhouse gases have contributed significantly to the oceans’ warming at a rate 22 times more than the atmosphere since 1950. Enhanced evaporation from warmer seas fuels heavier downpours and sequences of storms.

Polar ice is melting at rates unforeseen in the 1990s. As meltwater seeps down to lubricate their base, some Greenland outlet glaciers are moving 14 kilometers per year, twice as fast as in 2001, making linear projections for sea level rise this century no longer applicable. North Atlantic freshening — from melting ice and Arctic rainfall — is shifting the circulation pattern that has helped stabilize climates for millennia. Indeed, the slowing of the Ocean Conveyor Belt and the degree of storm destructiveness are occurring at rates and intensities that past models had projected would occur much later on in this century.

Hurricane Katrina



Warm ocean waters fuel hurricanes. This image depicts the three-day average of sea surface temperatures (SSTs) from August 25-27, 2005, and the growing breadth of Hurricane Katrina as it passed over the warm Gulf of Mexico. Yellow, orange and red areas are at or above 82°F (27.7°C), the temperature needed for hurricanes to strengthen. By late August SSTs in the Gulf were well over 90°F (32.2°C).

Source: NASA/Goddard Space Flight Center/Scientific Visualization Studio

Nonetheless, if we drastically reduce greenhouse gas emissions, our climate may reach a new and potentially acceptable equilibrium, affording a modicum of predictability. Doing so, however, requires a more sustainable energy mix that takes into account health and environmental concerns, as well as economic feasibility to power our common future. At this time, energy prices and supplies, political conflicts and climate instability are converging to stimulate the development of a new energy plan.

Expanded use of new energy-generation and efficiency-enhancing technologies, involving green buildings, solar, wind, tidal, geothermal, hybrids and combined cycle energy systems, can become the engine of growth for this century. The financial sector, having first sensed the integrated economic impacts of global climate change, has a special role to play: to help develop incentivizing rewards, rules and regulations.

This report examines a wide spectrum of physical and biological risks we face from an unstable climate. It also aims to further the development of healthy, safe and economically feasible energy solutions that can help stabilize the global climate system. These solutions should also enhance public health, improve energy security and stimulate economic growth.

– Paul Epstein and Evan Mills

## EXECUTIVE SUMMARY

Climate is the context for life on earth. Global climate change and the ripples of that change will affect every aspect of life, from municipal budgets for snowplowing to the spread of disease. Climate is already changing, and quite rapidly. With rare unanimity, the scientific community warns of more abrupt and greater change in the future.

Many in the business community have begun to understand the risks that lie ahead. Insurers and reinsurers find themselves on the front lines of this challenge since the very viability of their industry rests on the proper appreciation of risk. In the case of climate, however, the bewildering complexity of the changes and feedbacks set in motion by a changing climate defy a narrow focus on sectors. For example, the effects of hurricanes can extend far beyond coastal properties to the heartland through their impact on offshore drilling and oil prices. Imagining the cascade of effects of climate change calls for a new approach to assessing risk.

The worst-case scenarios would portray events so disruptive to human enterprise as to be meaningless if viewed in simple economic terms. On the other hand, some scenarios are far more positive (depending on how society reacts to the threat of change). In addition to examining current trends in events and costs, and exploring case studies of some of the crucial health problems facing society and the natural systems around us, “Climate Change Futures: Health, Ecological and Economic Dimensions” uses scenarios to organize the vast, fluid possibilities of a planetary-scale threat in a manner intended to be useful to policymakers, business leaders and individuals.

Most discussions of climate impacts and scenarios stay close to the natural sciences, with scant notice of the potential economic consequences. In addition, the technical literature often “stovepipes” issues, zeroing in on specific types of events in isolation from the real-world mosaic of interrelated vulnerabilities, events and impacts. The impacts of climate change cross national borders and disciplinary lines, and can cascade through many sectors. For this reason we all have a stake in adapting to and slowing the rate of climate change. Thus, sound policymaking demands the attention and commitment of all.

While stipulating the ubiquity of the threat of climate change, understanding the problem still requires a lens through which the problem might be approached. “Climate Change Futures” focuses on health. The underlying premise of this report is that climate change will affect the health of humans as well as the ecosystems and species on which we depend, and that these health impacts will have economic consequences. The insurance industry will be at the center of this nexus, both absorbing risk and, through its pricing and recommendations, helping business and society adapt to and reduce these new risks. Our hope is that Climate Change Futures (CCF) will not only help businesses avoid risks, but also identify opportunities and solutions. An integrated assessment of how climate change is now adversely affecting and will continue to affect health and economies can help mobilize the attention of ordinary citizens around the world and help generate the development of climate-friendly products, projects and policies. With early action and innovative policies, business can enhance the world’s ability to adapt to change and help restabilize the climate.

## WHY SCENARIOS?

CCF is not the first report on climate change to use scenarios. The Intergovernmental Panel on Climate Change (IPCC) employs six of the very long-term and very broad scenarios representative of the many scenarios considered. Other organizations have explored scenarios of climate trajectories, impacts for some sectors and the mix of energy sources, to explore the potential consequences of trends and actions taken today. Scenarios are not simple projections, but are stories that present alternative images of how the future might unfold. Handled carefully, scenarios can help explore potential consequences of the interplay of multiple variables and thereby help us to make considered and comprehensive decisions.

The IPCC scenarios, contained in the Special Report on Emissions Scenarios (SRES), make projections into the next century and beyond and assume that climate change will be linear and involve gradual warming. But events of the last five years have overtaken the initial SRES scenarios. Climate has changed faster and more unpredictably than the scenarios outlined. Many of the phenomena assumed to lie decades in the future are already well underway. This faster pace of change on many fronts indicates that more sector-specific, short-term scenarios are needed.

With this in mind, the CCF scenarios are designed to complement the far-reaching IPCC framework. Drawing upon the full-blown, long-term scenarios offered by the IPCC, we have developed two scenarios that highlight possibilities inadequately considered in past assessments of climate change impacts.

Both CCF scenarios envision a climate context of gradual warming with growing variability and more weather extremes. Both scenarios are based on “business-as-usual,” which, if unabated, would lead to doubling of atmospheric CO<sub>2</sub> from pre-industrial values by mid-century. Both are based on the current climate trends for steady warming along with an increase in extremes, with greater and costlier impacts. The compilation of extreme weather events of all types shows a clear increase over the past decade in the number of extremes occurring in both hemispheres (see figure below).

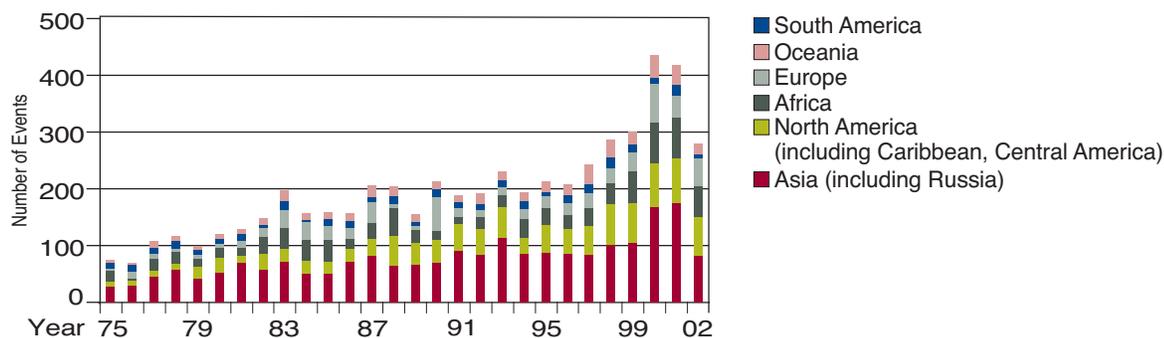
Overall costs from catastrophic weather-related events rose from an average of US \$4 billion per year during the 1950s, to US \$46 billion per year in the 1990s, and almost double that in 2004. In 2004, the combined weather-related losses from catastrophic and small events were US \$107 billion, setting a new record. (Total losses in 2004, including non-weather-related losses, were US \$123 billion; Swiss Re 2005a). With Hurricanes Katrina and Rita, 2005 had, by September, broken all-time records yet again. Meanwhile, the insured percentage of catastrophic losses nearly tripled from 11% in the 1960s to 26% in the 1990s and reached 42% (US \$44.6 billion) in 2004 (all values inflation-corrected to 2004 dollars; Munich Re NatCatSERVICE).

As an insurer of last resort, the US Federal Emergency Management Agency has experienced escalating costs for natural disasters since 1990. Moreover, in

## KEY POINTS

1. Warming favors the spread of disease.
2. Extreme weather events create conditions conducive to disease outbreaks.
3. Climate change and infectious diseases threaten wildlife, livestock, agriculture, forests and marine life, which provide us with essential resources and constitute our life-support systems.
4. Climate instability and the spread of diseases are not good for business.
5. The impacts of climate change could increase incrementally over decades.
6. Some impacts of warming and greater weather volatility could occur suddenly and become widespread.
7. Coastal human communities, coral reefs and forests are particularly vulnerable to warming and disease, especially as the return time between extremes shortens.
8. A more positive scenario is that climate reaches a new equilibrium, allowing a measure of adaptation and the opportunity to rapidly reduce the global environmental influence of human activities, namely fossil fuel combustion and deforestation.
9. A well-funded, well-insured program to develop and distribute a diverse suite of means to generate energy cleanly, efficiently and safely offers enormous business opportunities and may present the most secure means of restabilizing the climate.
10. Solutions to the emerging energy crisis must be thoroughly scrutinized as to their life cycle impacts on health and safety, environmental integrity, global security and the international economy.

Extreme Weather Events by Region



These data are taken from EMDAT (Emergency Events Database) from 1975 to 2002. Compiled by the Center for Research on the Epidemiology of Disasters (CRED) at the Université-Catholique de Louvain in Brussels, Belgium, this data set draws from multiple disaster relief organizations (such as OFDA and USAID), and is therefore skewed toward events that have large human impacts. The data taken from EMDAT were created with the initial support of WHO and the Belgian government.

the past decade, an increasing proportion of extreme weather events has been occurring in developed nations (Europe, Japan and the US) (see chart on page 6).

**The first impact scenario, or CCF-I,** portrays a world with an increased correlation and geographical simultaneity of extreme events, generating an overwhelming strain for some stakeholders. CCF-I envisions a growing frequency and intensity of weather extremes accompanied by disease outbreaks and infestations that harm humans, wildlife, forests, crops and coastal marine systems. The events and their aftermaths would strain coping capacities in developing and developed nations and threaten resources and industries, such as timber, tourism, travel and the energy sector. The ripples from the damage to the energy sector would be felt throughout the economy.

In CCF-I, an accelerated water cycle and retreat of most glaciers undermine water supplies in some regions and land integrity in others. Melting of permafrost (permanently frozen land) in the Arctic becomes more pronounced, threatening native peoples and northern ecosystems. And gradually rising seas, compounded by more destructive storms cascading over deteriorating barrier reefs, threaten all low-lying regions.

Taken in aggregate, these and other effects of a warming and more variable climate could threaten economies worldwide. In CCF-I, some parts of the developed world may be capable of responding to the disruptions, but the events would be particularly punishing for developing countries. For the world over, historical weather patterns would diminish in value as guides to forecasting the future.

**The second impact scenario, CCF-II,** envisions a world in which the warming and enhanced variability produce surprisingly destructive consequences. It explores a future rife with the potential for sudden, wide-scale health, environmental and economic impacts as climate change pushes ecosystems past tipping points. As such, it is a future inherently more chaotic and unpredictable than CCF-I.

Some of the impacts envisioned by the second scenario are very severe and would involve catastrophic, widespread damages, with a world economy beset by increased costs and chronic, unmanageable risks. Climate-related disruptions would no longer be contained or confined.

Threshold-crossing events in both terrestrial and marine systems would severely compromise resources and ecological functions, with multiple consequences for the species that depend upon them. For example:

- Repeated heat waves on the order of the 2003 and 2005 summers could severely harm populations, kill livestock, wilt crops, melt glaciers and spread wildfires.
- The probability of such extreme heat has already increased between two and four times over the past century and, based on an IPCC climate scenario, more than half the years by the 2040s will have summers warmer than that of 2003.
- Chronic water shortages would become more prevalent, especially in semi-arid regions, such as the US West.
- With current usage levels, more environmentally displaced persons and a changing water cycle, the number of people suffering water stress and scarcity today will triple in two decades.

## VULNERABILITIES IN THE ENERGY SECTOR



Image: Photodisc

- Heat waves generate blackouts.
- Sequential storms disrupt offshore oil rigs, pipelines, refineries and distribution systems.
- Diminished river flows reduce hydroelectric capacity and impede barge transport.
- Melting tundra undermines pipelines and power transmission lines.
- Warmed inland waters shut down power plant cooling systems.
- Lightning claims rise with warming.

Each stage in the life cycle of oil, including exploration, extraction, transport, refining and combustion, carries hazards for human health and the environment. More intense storms, thawing permafrost and dried riverbeds, make every stage more precarious.

Other non-linear impact scenarios include:

- Widespread diebacks of temperate and northern forests from drought and pests.
- Coral reefs, already multiply stressed, collapse from the effects of warming and diseases.
- Large spikes occur in property damages from a rise of major rivers. (A 10% increase in flood peak would produce 100 times the damage of previous floods, as waters breach dams and levees.)
- Severe storms and extreme events occurring sequentially and concurrently across the globe overwhelm the adaptive capacities of even developed nations; large areas and sectors become uninsurable; major investments collapse; and markets crash.

CCF-II would involve blows to the world economy sufficiently severe to cripple the resilience that enables affluent countries to respond to catastrophes. In effect, parts of developed countries would experience developing nation conditions for prolonged periods as a result of natural catastrophes and increasing vulnerability due to the abbreviated return times of extreme events.

Still, CCF-II is not a worst-case scenario.

A worst-case scenario would include large-scale, non-linear disruptions in the climate system itself — slippage of ice sheets from Antarctica or Greenland, raising sea levels inches to feet; accelerated thawing of permafrost, with release of large quantities of methane; and shifts in ocean thermohaline circulation (the stabilizing ocean “conveyor belt”).

Finally, there are scenarios of climate stabilization. Restabilizing the climate will depend on the global-scale implementation of measures to reduce greenhouse gas emissions. Aggressively embarking on the path of non-fossil fuel energy systems will take planning and substantive financial incentives — not merely a handful of temporizing, corrective measures.

This assessment examines signs and symptoms suggesting growing climate instability and explores some of the expanding opportunities presented by this historic challenge.

## APPLYING THE SCENARIOS

In choosing how to apply the two impact scenarios, we have focused on case studies of specific health and ecological consequences that extend beyond the more widely studied issue of property damages stemming from warming and natural catastrophes. In each case study, we identify current trends underway and envision the future consequences for economies, social stability and public health.

Infectious diseases have resurged in humans and in many other species in the past three decades. Many factors, including land-use changes and growing poverty, have contributed to the increase. Our examination of malaria, West Nile virus and Lyme disease explores the role of warming and weather extremes in expanding the range and intensity of these diseases and both linear and non-linear projections for humans and wildlife.

The rising rate of asthma (two to threefold increase in the past two decades; fourfold in the US) receives special attention, as air quality is affected by many aspects of a changing climate (wildfires, transported dust and heat waves), and by the inexorable rise of atmospheric CO<sub>2</sub> in and of itself, which boosts ragweed pollen and some soil molds.

We also examine the public health consequences of natural catastrophes themselves, including heat waves and floods. An integrated approach exploring linkages is particularly useful in these instances, since the stovepipe perspective tends to play down the very real health consequences and the manifold social and economic ripples stemming from catastrophic events.

Another broad approach of the CCF scenarios is to study climate change impacts on ecological systems, both managed and natural. We examine projections for agricultural productivity that, to date, largely omit the potentially devastating effects of more weather extremes and the spread of pests and pathogens. Crop losses from pests, pathogens and weeds could rise from the current 42% to 50% within the coming decade.

# THE CASE STUDIES IN BRIEF

## Infectious and Respiratory Diseases



**Malaria** is the deadliest, most disabling and most economically damaging mosquito-borne disease worldwide. Warming affects its range, and extreme weather events can precipitate large outbreaks. This study documents the fivefold increase in illness following a six-week flood in Mozambique, explores the surprising role of drought in northeast Brazil, and projects changes for malaria in the highlands of Zimbabwe.

*3,000 African children die each day from malaria.  
Image: Pierre Viot/WHO*



**West Nile virus (WNV)** is an urban-based, mosquito-borne infection, afflicting humans, horses and more than 138 species of birds. Present in the US, Europe, the Middle East and Africa, warm winters and spring droughts play roles in amplifying this disease. To date, there have been over 17,000 human cases and over 650 deaths from WNV in North America.

*Culex pipiens mosquitoes breed in city drains.  
Image: Biopix.dk*



**Lyme disease** is the most widespread vector-borne disease in the US and can cause long-term disability. Lyme disease is spreading in North America and Europe as winters warm, and models project that warming will continue to shift the suitable range for the deer ticks that carry this infection.

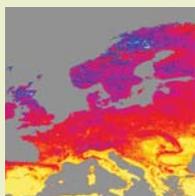
*The deer tick that carries Lyme disease.  
Image: Scott Bauer/USDA Agricultural Research Service*



**Asthma** prevalence has quadrupled in the US since 1980, and this condition is increasing in developed and underdeveloped nations. New drivers include rising CO<sub>2</sub>, which increases the allergenic plant pollens and some soil fungi, and dust clouds containing particles and microbes coming from expanding deserts, compounding the effects of air pollutants and smog from the burning of fossil fuels.

*Asthma rates have quadrupled in the US since 1980.  
Image: Daniela Spyropoulou/Dreamstime*

## Extreme Weather Events



**Heat waves** are becoming more common and more intense throughout the world. This study explores the multiple impacts of the highly anomalous 2003 summer heat wave in Europe and the potential impact of such "outlier" events elsewhere for human health, forests, agricultural yields, mountain glaciers and utility grids.

*Temperatures in 2003 were 6°C (11°F) above long-term summer averages.  
Image: NASA/Earth Observatory*

# THE CASE STUDIES IN BRIEF



**Floods** inundated large parts of Central Europe in 2002 and had consequences for human health and infrastructure. Serious floods occurred again in Central Europe in 2005. The return times for such inundations are projected to decrease in developed and developing nations, and climate change is expected to result in more heavy rainfall events.

*Floods have become more common on most continents.  
Image: Bill Haber/AP*

## Natural and Managed Systems



**Forests** are experiencing numerous pest infestations. Warming increases the range, reproductive rates and activity of pests, such as spruce bark beetles, while drought makes trees more susceptible to the pests. This study examines the synergies of drought and pests, and the dangers of wildfire. Large-scale forest diebacks are possible, and they would have severe consequences for human health, property, wildlife, timber and Earth's carbon cycle.

*Droughts and pest infestations contribute to the rise in forest fires.  
Image: John McColgan, Bureau of Land Management, Alaska Fire Service*



**Agriculture** faces warming, more extremes and more diseases. More drought and flooding under the new climate, and accompanying outbreaks of crop pests and diseases, can affect yields, nutrition, food prices and political stability. Chemical measures to limit infestations are costly and unhealthy.

*Healthy crops need adequate water and freedom from pests and disease.  
Image: Ruta Saulyte/Dreamstime*



**Marine ecosystems** are under increasing pressure from overfishing, excess wastes, loss of wetlands, and diseases of bivalves that normally filter and clean bays and estuaries. Even slightly elevated ocean temperatures can destroy the symbiotic relationship between algae and animal polyps that make up coral reefs, which buffer shores, harbor fish and contain organisms with powerful chemicals useful to medicine. Warming seas and diseases may cause coral reefs to collapse.

*Coral reefs nourish fish and buffer shorelines.  
Image: Oceana*



**Water**, life's essential ingredient, faces enormous threats. Underground stores are being overdrawn and underfed. As weather patterns shift and mountain ice fields disappear, changes in water quality and availability will pose growth limitations on human settlements, agriculture and hydropower. Flooding can lead to water contamination with toxic chemicals and microbes, and natural disasters routinely damage water-delivery infrastructure.

*Millions of people walk four hours per day to obtain clean water.  
Image: Pierre Viot/WHO*

## THE INSURER'S OVERVIEW: A UNIQUE PERSPECTIVE

The concept of risk looms over all these impacts. Since the insurance industry provides a mechanism for spreading risk across time, over large geographical areas, and among industries, it provides a natural window into the broad macroeconomic effects of climate change.

The core business of insurance traditionally involves technical strategies for loss reduction as well as financial strategies for risk management and risk spreading. In both core businesses, as well as activities in financial services and asset management, the insurance sector is increasingly vulnerable to climate change. As such, insurers are impacted by and stand to be prime movers in responding to climate change. Insurers, states the Association of British Insurers, must be equipped to analyze the new risks that flow from climate change and help customers manage these risks. As real estate prices rise and more people inhabit vulnerable coasts and other at-risk areas, the number and intensity of weather-related disasters have also risen, and associated losses continue to rise despite substantial resources devoted to disaster preparedness and recovery.

The insurance perspective provides a useful access point for the Climate Change Futures project because of the macroeconomic role the insurance industry plays. Insurance is a major, time-tested method for adapting to change and any phenomenon that jeopardizes the ability of the global insurance industry to play this role will have a major disruptive effect. Moreover, instability is not good for business and unstable systems are prone to sudden change.

These major risks are an obvious concern for insurers and reinsurers, but they affect society as a whole. In the words of one prominent insurance executive, it's the clients who buy insurance who insure each other. The insurance industry provides the expertise and capacity to absorb and spread the risk, and reinsurers are vulnerable if those insurers that they insure are vulnerable.

## POLICY MEASURES FOR EVERYONE

The Kyoto Treaty notwithstanding, and despite strong greenhouse gas reduction commitments by some

governments, little action has been taken by most governments or businesses to address the potential costs of climate change. As all insurers know, however, risk does not compliantly bow to the political or business agenda. As the costs of inaction rise, the impetus for practical action by all stakeholders becomes all the more urgent. In the next several years, all nations will have energy, environmental and economic choices to make. No matter what scenarios are used, the initial focus should be on "no regrets" measures that will have beneficial consequences — and on formulating contingency plans that will work in different conceivable futures.

## BUILDING AWARENESS

Understanding the risks and opportunities posed by climate change is the first step toward taking corrective measures. A broad educational program on the basic science and societal impacts of climate change is needed to better inform businesses, regulators, governments, international bodies and the public.

Regulators in every industry as well as governments need to use this knowledge to frame regulations in climate-friendly ways. Special attention is needed to identify misaligned incentives and identify throwbacks that come from earlier carbon-indifferent times.

Companies can study their own risks stemming from carbon dioxide emissions and incorporate their analyses into their strategy, planning and operations.

Insurers can amass more pertinent information and continue to improve climate risk assessment methods to overcome the lack of historical guidelines for assessing future climate. They can examine the new exposures, including liabilities. Climate change challenges all aspects of investments and insurance, and these risks must be better integrated into planning products, programs and portfolios.

Investors can evaluate their portfolios for climate risks and opportunities. Mainstream financial analyses can include climate issues in investment decisions. The capital markets can help educate clients about risks and strategies as well as the financial opportunities presented by new technologies.

All citizens can learn about their own "carbon footprint" and the implications of their own consumption and political participation.

## THE CCF PROJECT IN BRIEF

The CCF project was developed from the concerns of three institutions, the Center for Health and the Global Environment at Harvard Medical School, Swiss Re and the United Nations Development Programme, regarding the rising risks that climate change presents for health, Earth systems and economies.

### History

**September 2003:** Scoping Conference  
United Nations Headquarters, New York City

**June 2004:** Executive Roundtable  
Swiss Re Centre for Global Dialogue  
Rüschlikon, Switzerland

**August 2004:** Workshop  
Swiss Re  
Armonk, NY

**November 2005:** Report Released  
American Museum of Natural History, New York City

### Unique Aspects of CCF

- The integration of corporate “stakeholders” directly in the assessment process.
- A combined focus on the physical, biological and economic impacts of climate change.
- Anticipation of near-term impacts, rather than century-scale projections.
- Inclusion of diseases of humans, other animals, land plants and marine life, with their implications for resources and nature’s life-support systems.
- Involvement of experts from multiple fields: public health, veterinary medicine, agriculture, marine biology, forestry, ecology, economics and climatology and conservation biology.
- Scenarios of plausible futures with both gradual and step-wise change.
- Policy recommendations aimed at optimizing adaptation and mitigation.
- A framework for planning for climate-related surprises.

## RAPIDLY REDUCING CARBON OUTPUT

Reducing the output of greenhouse gases on a global scale will require a concerted effort by all stakeholders and a set of integrated, coordinated policies. A framework for solutions is the following:

- Significant, financial incentives for businesses and consumers.
- Elimination of misaligned or “perverse” incentives that subsidize carbon-based fuels and environmentally destructive practices.
- A regulatory and institutional framework designed to promote sustainable use of resources and constrain the generation of wastes.

The critical issue is the order of magnitude of the response. The first phase of the Kyoto Protocol calls for a 6-7% reduction of greenhouse gas emissions below 1990 levels by 2012, while the IPCC calculates that a 60-70% reduction in emissions is needed to stabilize atmospheric concentrations of greenhouse gases. The size of the investment we make will depend on our understanding of the problem and on the pace of climate change.

The use of scenarios allows us to envision a future with impacts on multiple sectors and even climate shocks. “Imagining the unmanageable” can help guide constructive short-term measures that complement planning for the potential need for accelerated targets and timetables.

With an appreciation of the risks we face, actions to address the problem will become more palatable. Individuals and the institutions in which they are active can alter consumption patterns and political choices, which can influence accepted norms and markets. Corporate executive managers can declare their commitment to sustainability principles, such as those enunciated by Ceres<sup>1</sup> and the Carbon Disclosure Project<sup>2</sup>, and those like the Equator Principles<sup>3</sup> to guide risk assessment, reporting practices and investment policies.

1. Ceres is a national network of investments funds, environmental organizations and other public interest groups working to advance environmental stewardship on the part of business. <http://www.ceres.org/>

2. The Carbon Disclosure Project provides a secretariat for the world’s largest institutional investor collaboration on the business implications of climate change. <http://www.cdproject.net>

3. The Equator Principles provide an industry approach for financial institutions in determining, assessing and managing environmental and social risk in project financing. <http://www.equator-principles.com/principles.shtml>

Regulators and governments can employ financial instruments to create market signals that alter production and consumption. They can streamline subsidies so that climate-friendly investments of public and private funds are encouraged, and eliminate perverse incentives for oil and coal exploration and consumption. They can finance public programs using low-carbon technologies and formulate tax incentives that encourage consumers and producers to pursue climate-friendly activities. They can revise government procurement practices to stimulate demand, set up a regulatory framework for carbon trading and help construct the alternative energy infrastructure.

Industry and the financial sector, in partnership with governments and United Nations agencies, can establish a clean development fund to transfer new technologies, and finance and insure new manufacturing capability in developing nations. Insurers can influence the behavior of other businesses through revisions in coverage (easing the risk of adopting cleaner technologies), by developing their own expertise in low-carbon technologies and by working jointly with their clients to develop new products. Investors can find creative ways to incentivize the movement of investment capital toward renewable energy and away from polluting industries. Institutional investors, such as state and union pension funds, can play a pivotal role in this process. This can take the form of project finance or innovative financial instruments. The capital markets can foster the development of carbon risk-hedging products, such as derivatives, and promote secondary markets in carbon securities.

These measures would be sound even in the absence of climate change, as disaster losses will rise due to increased population and exposures alone. Similarly, efforts to reduce greenhouse gas emissions are typically cost-effective in their own right and bring multiple benefits, including reduced air pollution.

## PLANNING AHEAD

Climate can change gradually, allowing some degree of adaptation. But even gradual change can be punctuated by surprises. Hurricane Katrina was of such breadth and magnitude as to overwhelm defenses, and could mark a turning point in the pace with which the world addresses climate change.

The compounding influences of vulnerabilities, along with the increasing destructiveness of moisture-laden storms, have been a tragic wakeup call for all. As we embark on a publicly funded recovery program of enormous magnitude, the reconstruction process may itself set the global community on a course thought unlikely in the very recent past.

Planning on a global scale to restructure the development paradigm is not something societies have often done. At the end of World War II, following three decades of war, the dust bowl and depression, the Bretton Woods agreements established new monetary signals. Complemented by the Marshall Plan fund and the financial incentives embedded into the US GI bill, the combined “carrots and sticks” ushered in a productive post-war economic order.

The health, ecological and economic consequences of our dependence on fossil fuels are widespread and are becoming unsustainable. Will the triple crises of energy, the environment and ultimately the economy precipitate another “time out” in which all stakeholders come together to form the blueprints for a new financial architecture?

As we brace for more surprises we must prepare a set of reinforcing financial instruments that can rapidly jump-start a transition away from fossil fuels. The challenge of climate change presents grave risks and enormous opportunities, and the clean energy transition may be just the engine that takes us into a healthier, more productive, stable and sustainable future.

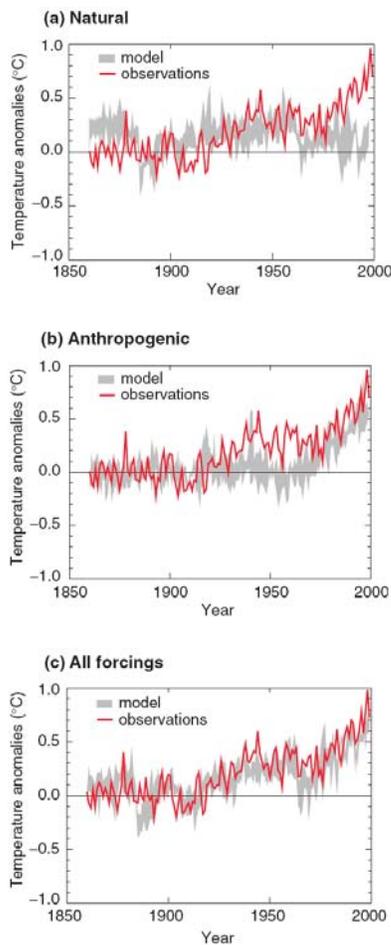


**PART I:**  
*The Climate Context Today*

## THE PROBLEM: CLIMATE IS CHANGING, FAST

The proposition that climate change poses a threat because of an enhanced greenhouse effect inevitably begs questions. Without greenhouse gases such as CO<sub>2</sub> trapping heat (by absorbing long-wave length radiation from the earth's surface), the planet would be so cold that life as we know it would be impossible. For more than two million years, Earth has alternated between two states: long periods of icy cold interrupted by relatively short respites of warmth. During glacial times, the polar ice caps and Alpine glaciers grow; during the interglacial periods, the North Polar cap shrinks, as do Alpine glaciers.

Figure 1.1 Simulated Annual Global Mean Surface Temperatures



The simulations represented by the band in (a) were done with only natural forcings: solar variation and volcanic activity. Those in (b) were done with anthropogenic forcings: greenhouse gases and an estimate of sulphate aerosols. Those encompassed by the band in (c) were done with both natural and anthropogenic forcings included. The best match with observations is obtained in (c) when both natural and anthropogenic factors are included.

These charts formed the basis for the IPCC's conclusion that human activities were contributing to climate change.  
Image: IPCC 2001

Up until the 20th century, these cycles were driven by the variations in the tilts, wobbles and eccentricities of Earth's orbit — the Milankovitch cycles, named for the Serbian mathematician who deciphered them. The temperature changes from the industrial revolution on, however, can only be explained by combining natural variability with anthropogenic influences (Houghton et al. 2001) (see figure 1.1). Recent calculations of these long-wave cycles project that the current interglacial period — the Holocene — was not about to end any time soon (Berger and Loutre 2002).

Much of human evolution took place during this latest glacial period; our ancestors survived the cold periods and prospered during the warmer interregnums, particularly the most recent span that encompassed the birth and efflorescence of civilization. So, if the climate is warming, what's the problem?

Climate change may not be a threat to the survival of our species, but it is a threat to cultures, civilizations and economies that adapt to a particular climate at a particular time. Through history, humans as a species have survived climate changes and those groups that made it through the adversity of "cold reversals" did so by calling on their capacities to communicate, cooperate and plan ahead (Calvin 2002). But many civilizations have also perished when they could not adapt fast enough. Societies adapt to their current conditions, taking a gamble that those circumstances will continue or change gradually. Never has this been more true than in the recent past: The explosion of human numbers and the miracles of modern economic development have all taken place during the extraordinary climate stability that has prevailed since the early 19th century. The five-billion-person increase in human population during that period occurred against the backdrop of a climate that was neither too warm, too cold, too dry, nor too wet. In the past, climate change has been driven by the Milankovitch cycles, volcanic eruptions and the movement of continents. Now, ironically, thanks in part to the nurturing climate of recent centuries, humanity has become a large enough presence on the planet to itself affect climate. As the evolutionary biologist E.O. Wilson put it, "Humanity is the first species to become a geophysical force."

In its Third Assessment Report in 2001 (Houghton et al. 2001), the IPCC came to the same insight. The report's four primary conclusions were: Climate is changing; humans are contributing to those changes; weather is becoming more extreme; and biological systems are responding to the warming on all continents

(see McCarthy et al. 2001). As glaciologist Richard Alley put it succinctly, addressing skeptical staffers from Congress at a 2004 conference convened by the American Association for the Advancement of Science, "Get over it, climate is warming."

Humans affect climate primarily through the combustion of fossil fuels, which pump carbon dioxide into the atmosphere. Atmospheric levels of carbon dioxide have consistently tracked global temperatures. For the past 420,000 years, as recorded in ice cores taken from Vostok in Antarctica, CO<sub>2</sub> levels in the lower atmosphere have remained within an envelope ranging from 180 parts per million (ppm) to 280 ppm (Petit et al. 1999). CO<sub>2</sub> levels are now 380 ppm, most likely their highest level in 55 million years (Seffan et al. 2004a).

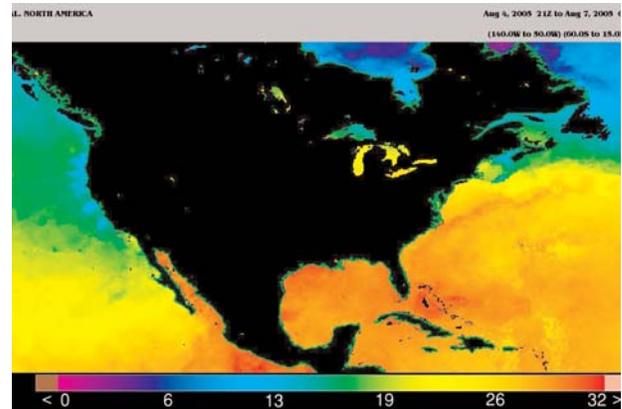
These levels have been reached despite the fact that ocean and terrestrial "carbon sinks" have absorbed enormous amounts of CO<sub>2</sub> since the industrial revolution (see Mann et al. 1998). The combustion of fossil fuels (oil, coal and natural gas) generates 6 billion tons of carbon annually (one ton for each person on Earth). Meanwhile, warmer and more acidic oceans (from the excess CO<sub>2</sub> already absorbed) take up less heat and less CO<sub>2</sub> (Kortzinger et al. 2004).

In essence, humans are tinkering with the operating systems that control energy distribution on the planet. As fossil fuels are burned, their excess by-products accumulate in the lower atmosphere, reinforcing the thin blanket that insulates the earth. Warming of the atmosphere heats the oceans, melts ice and increases atmospheric water vapor — shifting weather patterns across the globe.

The world's oceans dominate global climate. Because of their staggering capacity to store heat, the oceans are the main drivers of weather and the stabilizers of climate. The relationship between the oceans and the atmosphere is marked by exchanges of heat on scales that range from the immediate to hundreds of years. The oceans have been warming along with the rest of the globe, down to two miles below the surface (Levitus et al. 2000). It appears that the deep ocean is the repository for the global warming of the 20th century, having absorbed 84% of the warming (Barnett et al. 2005).

Intermittently, the ocean releases some of its huge store of heat into the atmosphere. Thus a certain degree of warming already in place has yet to become manifest.

Figure 1.2 The Warming Tropical Seas

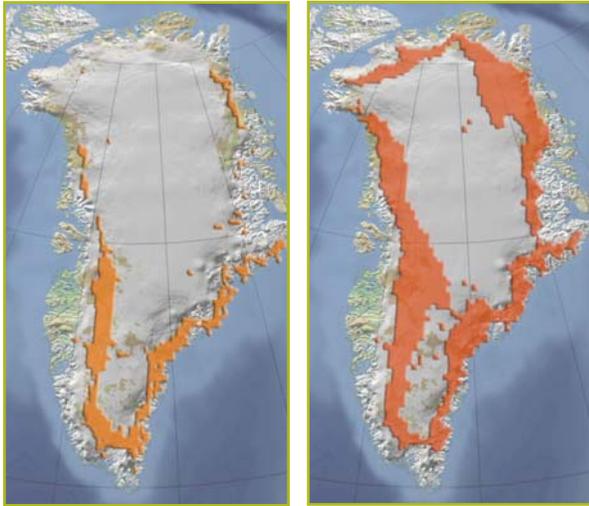


Satellite images showing warmed Atlantic and Pacific Oceans and an especially warm Gulf of Mexico in early August 2005. The tropical oceans have become warmer and saltier (from increased evaporation; Curry et al. 2003), and warmer sea surfaces evaporate rapidly and provide moisture that fuels hurricanes. Image: NOAA

In several ways the oceans have already begun to respond. Warming of the atmosphere and the deep oceans is altering the world water cycle (Dai et al. 1998; WMO 2004; Trenberth 2005). Ocean warming (and land surface warming) increase evaporation, and a warmer atmosphere holds more water vapor [6% more for each 1°C (1.8°F) warming; Trenberth and Karl 2003]. Water vapor has increased over the US some 15% over the past two decades (Trenberth et al. 2003).

One of the less appreciated natural heat-trapping gases is water vapor. Greater evaporation leads to greater warming. Higher humidity also fuels more intense, tropical-like downpours, while warming, evaporation and parching of some of Earth's surface creates low-pressure pockets that pull in winds and weather. The increased energy in the system intensifies weather extremes from several perspectives and the accelerated hydrological (water) cycle is associated with the increasingly erratic and severe weather patterns occurring today. As models projected (Trenberth 2005), some areas are becoming drier due to more heat and evaporation, while others are experiencing recurrent flooding. And when heavy rains hit parched regions they are poorly absorbed and this can lead to flooding. Part of the increased vapor comes from melting of the cryosphere — ice cover in polar and Alpine regions. Over this century, Arctic temperatures are expected to increase twice as fast as in the world at large (ACIA 2005), a chief reason being that more heat is absorbed by the expanding open ocean and less is reflected from the shrinking ice cover.

Figure 1.3 Greenland



Extent of summer ice melt in Greenland in 1992 (left) and in 2002 (right). Greenland is losing mass at 3% per decade and melting rates have accelerated. Melting in 2004 was occurring at 10 times the rates observed in 2000. Pools of meltwater are visible on the surface each summer and meltwater is percolating down through crevasses to lubricate the base. As the “rivers of ice” speed up, the potential for slippage of large glaciers from Greenland increases. Images: Clifford Grabhorn/ACIA 2005

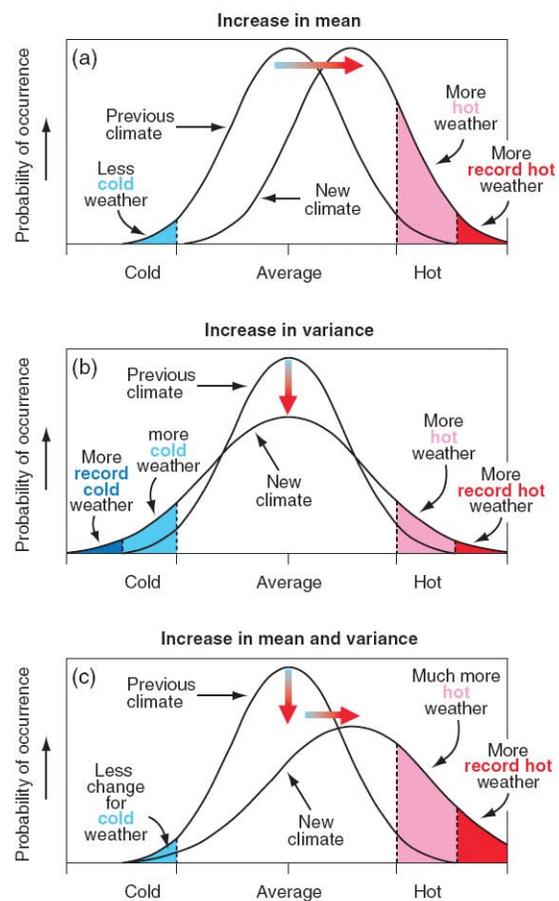
Sea ice covers approximately 75% of the Arctic Ocean surface. Ice and snow reflect 50-80% of the sunlight coming in, while open ocean absorbs about 85% (Washington and Parkinson 2005). Greenland and polar ice are losing mass at rates not thought possible until late in this century (Parkinson et al. 1999; Rothrock et al. 1999; ACIA 2005). The decrease in Earth’s reflectivity (albedo) when sea and alpine ice melts produces a “positive” feedback (Chapin et al. 2005), meaning that warming leads to further warming. Since 1978, ocean ice has been melting at 3% per decade, and there could be a threshold change in the globe’s reflectivity beyond which the system rapidly changes state.

Global warming is not occurring uniformly. The three warmest “hotspots” are Alaska, Northern Siberia and the Antarctic Peninsula. Since 1950, summer temperatures in these regions have increased 4-6°F (2-3°C) while winter temperatures have risen 8-10°F (4-5°C). Nights and winters — crucial in heat waves and important for crops — are also warming twice as fast as globally averaged temperatures (Easterling et al. 1997). Clouds contribute to warmer nights, while atmospheric circulation of winds and heat create disproportionate heating during winters. All of these changes — warmer nights and winters, and wider swings in weather — affect people, disease vectors and ecological systems.

## EXTREMES

One of the earliest and most noticeable changes detected as a result of recent warming has been an increase in extreme weather events. Over the last half-century, weather patterns have become more variable, with more frequent and more intense rainfall events (Karl et al. 1995; Easterling et al. 2000). As Earth adjusts to our rewriting of the climate script, there have been changes in the timing and location of precipitation, as well as more intense heat waves and prolonged droughts (Houghton et al. 2001).

Figure 1.4 Climate Change Alters the Distribution of Weather Events



Schematic showing the effect on extreme temperatures when (a) the mean temperature increases, (b) the variance increases, and when (c) both the mean and variance increase. The current climate appears to be a hybrid of (b) and (c); that is, the average temperature is warming and more hot and cold anomalies are occurring. Image: IPCC 2001

Table 1.1 Extreme Weather Events and Projected Changes

Confidence in observed changes (latter half of the 20th century)	Changes in phenomena	Confidence in projected changes (during the 21st century)
Likely	Higher maximum temperatures and more hot days <sup>a</sup> over nearly all land areas	Very likely
Very likely	Higher minimum temperatures, fewer cold days and frost days over nearly all land areas	Very likely
Very likely	Reduced diurnal temperature range over most land areas	Very likely
Likely, over many areas	Increase of heat index <sup>b</sup> over land areas	Very likely, over most areas
Likely, over many Northern Hemisphere mid- to high latitude land areas	More intense precipitation events <sup>c</sup>	Very likely, over many areas
Likely, in a few areas	Increased summer continental drying and associated risk of drought	Likely, over most mid-latitude continental interiors. (Lack of consistent projections in other areas)
Not observed in the few analyses available	Increase in tropical cyclone peak wind intensities <sup>d</sup>	Likely, over some areas
Insufficient data for assessment	Increase in tropical cyclone mean and peak precipitation intensities <sup>d</sup>	Likely, over some areas

<sup>a</sup> *Hot days* refers to a day whose maximum temperature reaches or exceeds some temperature that is considered a critical threshold for impacts on human and natural systems. Actual thresholds vary regionally, but typical values include 32°C, 35°C or 40°C (90°F, 95°F and 104°F).  
<sup>b</sup> *Heat index* refers to a combination of temperature and humidity that measures effects on human comfort.  
<sup>c</sup> For other areas, there are either insufficient data or conflicting analyses.  
<sup>d</sup> Past and future changes in tropical cyclone location and frequency are uncertain.

Source: IPCC 2001

While the amount of rain over the US has increased 7% over the past century, that increase camouflages more dramatic changes in the way this increased precipitation has been delivered. Heavy events (over 2 inches/day) have increased 14% and very heavy events (over 4 inches/day) have increased 20% (Groisman et al. 2004). The increased rate of heavy precipitation events is explained in great part by the tropical ocean surfaces (Curry et al. 2003) along with a heated atmosphere. The frequency and intensity of extremes are projected to increase in the coming decades (Houghton et al. 2001; Meehl and Tebaldi 2004; ABI 2005) (see Table 1.1).

Recent analysis of tropical cyclones (Emanuel 2005; Webster et al. 2005) found that their destructive power (a function of storm duration and peak winds) had more than doubled since the 1970s, and the frequency of large and powerful storms had increased, and that these changes correlated with ocean warming. Changes in the variance and strength of weather patterns accompanying global warming will most likely have far greater health and ecological consequences than will the warming itself.

Examples abound of the costs of weather anomalies. The most recent series of extremes occurred in the sum-

mer of 2005. In July, a heat wave, anomalous in its intensity, duration and geographic extent, enveloped the US and southern Europe. In the US particularly, records were exceeded in numerous cities. Phoenix, AZ experienced temperatures over 100°F for 39 consecutive days, while the mercury reached 129°F in Death Valley, CA. Drought turned a large swath of southern Europe into a tinderbox and when it ended with torrential rains, flooding besieged central and southern parts of the continent and killed scores.

## OUTLIERS AND NOVEL EVENTS

Beyond extremes, there are outliers, events greater than two or three standard deviations from the average that are literally off the charts. A symptom of an intensified climate system is that the extraordinary becomes more ordinary. We have already experienced major outlier events: the 2003 summer European heat wave was one such event—with temperatures a full six standard deviations from the norm. This event is addressed in depth in this report.

For developing nations, such truly exceptional events leave scars that retard development for years. It took years for Honduras to rebuild infrastructure damaged in the 1998 Hurricane Mitch, for example.

Wholly new types of events are also occurring, such as the twin Christmas windstorms of 1999 that swept through Central Europe in rapid succession (with losses totaling over US \$5 billion; RMS 2002), and the first ever hurricane recorded in the southern Atlantic that made landfall in Brazil in early 2004.

## CLIMATE PROJECTIONS

Over the next century the IPCC (Houghton et al. 2001) projects the climate to warm some 1.4-5.4°C (or 2.5-10°F). Multiple runs of climate models suggest that we may have vastly underestimated the role of positive feedbacks driving the system into accelerated change; and an ensemble of models extends the upper end of the range to 11°C (20°F) and variability becomes even more exaggerated (Stainforth et al. 2005). Andreae et al. (2005) project that a decrease in “cooling” sulfates also raises projections to 10°C (18°F). All the ranges are based on estimates as to how society will respond and adjust energy choices, as well as uncertainties regarding feedbacks. (“Negative” feedbacks help reinforce and bind systems, while “positive” ones contribute to their unraveling.)

Projections from recent observations (Cabanes et al. 2001; Cazanave and Nerem 2004, Church et al. 2004) have been made for sea level rise (SLR), and in the absence of collapses of ice sheets, SLR by the end of the century will be 1 to 3 feet (30-90 cm). With accelerated melting of Greenland and Antarctica ice sheets (De Angelis and Skvarca 2003; Scambros et al. 2004; Domack et al. 2005), these may be significant underestimates (Hansen 2005).

## CHANGES IN NATURAL MODES

Climate change may be altering oscillatory modes nested within the global climate system. The El Niño/Southern Oscillation (ENSO) phenomenon is one of Earth’s coupled ocean-atmospheric systems, helping to stabilize climate through its oscillations and by “letting off steam” every three to seven years. Warm ENSO events (El Niño) have in the past created warmer and wetter conditions overall, along with intense droughts in some regions. ENSO events are associated with weather anomalies that can precipitate “clusters” of illnesses carried by mosquitoes, water and rodents (Epstein 1999; Kovats et al. 1999) and property losses from extremes tend to spike during these anomalous years as well. Climate change may have already altered the ENSO phenomenon (Fedorov and Philander 2000; Kerr 2004; Wara et al. 2005), with current weather patterns reflecting the combination of natural variability and a changing baseline.

In Asia, the monsoons may be growing more extreme and less tied with ENSO (Kumar et al. 1999), as warming of Asia and melting of the Himalayas create low pressures, which draw in monsoons that have picked up water vapor from the heated Indian Ocean.

The North Atlantic Oscillation (NAO) is another climate mode and the one that governs windstorm activity in the Northeast US and in Europe. Global warming may also be altering this natural mode of climate variability (Hurrell et al. 2001), affecting winter and summer weather in the US and Europe, with implications for health, ecology and economies (Stenseth et al. 2002).

## THE CHANGING NORTH ATLANTIC

The overturning deep water in the North Atlantic Ocean is the flywheel that pulls the Gulf Stream north and drives the “ocean conveyor belt” or thermohaline circulation. Melting ice and more rain falling at high latitudes are layering fresh water near Greenland. Meanwhile, the tropical Atlantic has been warming and getting saltier from enhanced evaporation. This sets up an increased contrast in temperatures and pressures. The composite changes may be altering weather systems moving west and east across the Atlantic. These changes could be related to the following:

- Swifter windstorms moving east across to Europe.
- Heat waves in Europe from decreased evaporation off the North Atlantic.
- Ocean contrasts helping to propel African dust clouds across to the Caribbean and US.
- It is possible that more hurricanes will traverse the Atlantic east to west as pressures change (and as the fall season is extended).
- The layering of freshwater in the North Atlantic in contrast to warmer tropics and mid-latitudes may be contributing to nor’easters and cold winters in the Northeast US.

During the 1980s and 1990s, the two air systems (North and South) tended on average to be locked in a “positive phase” each winter. Modeling this interplay, Hurrell and colleagues (2001) found that Earth’s rising temperature — especially the energy released into the atmosphere by the overheated Indian Ocean — is affecting the behavior of this massive atmospheric system known as the NAO.

## DISCONTINUITIES

CLIVAR, Climate Variability and Predictability World Climate Research Programme, a collaborative effort that looks at long- as well as short-term variability, studies discontinuities. Several step-wise shifts in climate may already have occurred in the past three decades.

One step-wise climate shift may have occurred around 1976 (CLIVAR 1992). The eastern Pacific Ocean became warmer, as surface pressures and winds shifted across the Pacific. Between 1976 and 1998, El Niños became larger, more frequent and persisted longer than at any time according to records kept since 1887. The period included the two largest El Niños of the century, the return times decreased and the longest persisting El Niño conditions (five years and nine months; Trenberth 1997) eliminated pest-killing frosts in the southern and middle sections of the US. Termites proliferated in New Orleans.

Then, in 1998, another step-wise adjustment may have occurred, as the eastern Pacific turned cold (burying heat), becoming “The perfect ocean for drought” (Hoerling and Kumar 2003), as cool waters evaporate slowly. After this “correction,” the energized climate system has ushered in an anomalous series of years with unusually intense heat waves and highly destructive storms.

Finally, there is the question of the ocean circulation system that delivers significant heat to the North Atlantic region. Most models (Houghton et al. 2001) project slowing or collapse of the ocean conveyor belt — the pulley-like system of sinking water in the Arctic that drags warm water north and has helped to stabilize climate over millennia. The cold, dense, saline water that sinks as part of the conveyor belt in the North Atlantic has been getting fresher (Dickson et al. 2002; Curry et al. 2003; Curry and Mauritzen 2005), as melting ice flows into the ocean, and more rain falls at high latitudes and flows into the Arctic Sea (Peterson et al. 2002). This freshening may be reducing the vigor of the global circulation (Munk 2003; Wadhams and Munk 2004).

The dangers of disruption of ocean circulation involve the counterintuitive but real possibility that global warming might precipitate a sudden cooling in economically strategic parts of the globe as well as the prospect of an economically disastrous “flickering climate,” as climate lurches between cold and warm, and potentially tries to settle into a new state (Broecker 1997).

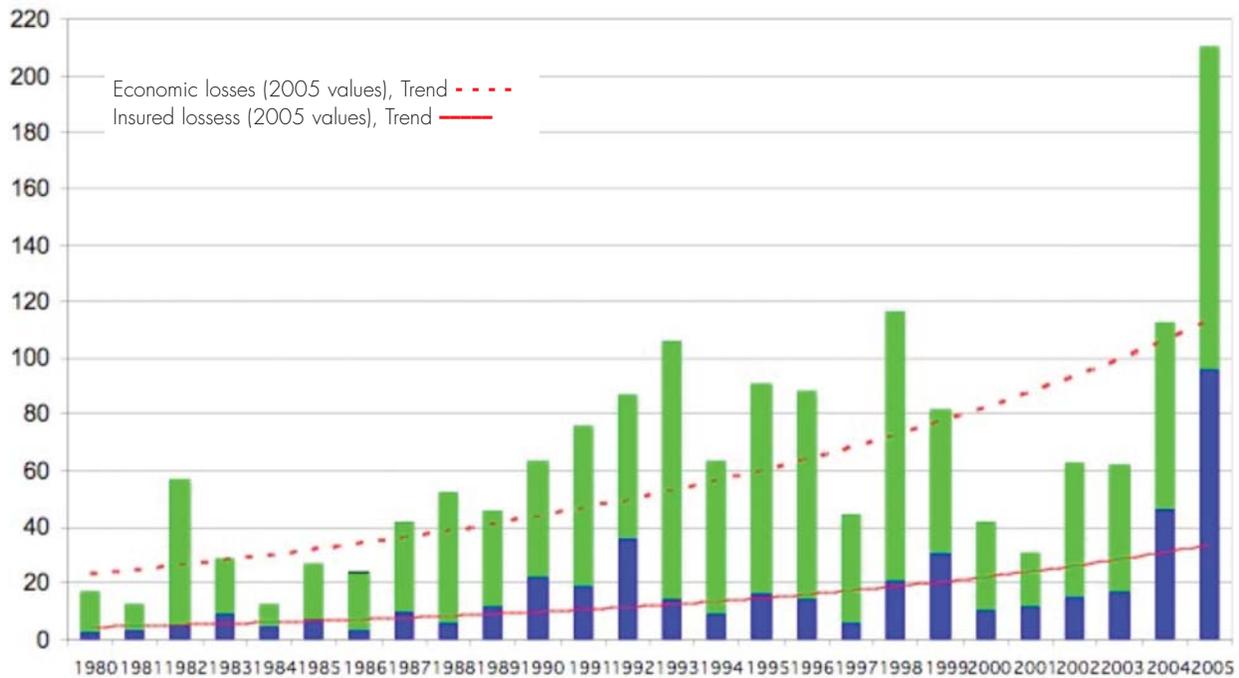
## TREND ANALYSES: EXTREME WEATHER EVENTS AND COSTS

The Chicago Mercantile Exchange estimates that about 25% of the US economy is affected by the weather (Cohen et al. 2001). Vulnerability to disasters varies with location and socioeconomic development. Vulnerabilities to damages also increase as the return times of disasters become shorter. More frequent, intense storms hitting the same region in sequence leave little time for recovery and resilience in developed as well as developing nations. The rapid sequences themselves increase vulnerability to subsequent events, and disasters occurring concurrently in multiple geographic locations increase the exposure of insurers, reinsurers, and others who must manage and spread risks.

The cost of climate events quickly spreads beyond the immediate area of impact, as was shown by studies of the consequences of the US \$10 billion European windstorms and Hurricane Floyd in the US in 1999 (IFRC and RCS 1999). To further develop the context for the scenarios, we first consider the trends in extreme weather events and associated costs, which set the stage for assessing the likelihood of more health, ecological and economic consequences of an unstable climate regime.

The number of weather-related disasters has already risen over the past century (EM-DAT 2005). The nature of the associated losses, however, varies considerably around the globe. In the past decade, more such events are occurring in the Northern Hemisphere (EM-DAT 2005), and the losses are beginning to be felt by all. The composition of event types has also been undergoing change, with a particularly notable increase in events with material consequences for health and nutrition in the developing world (extreme temperature episodes, epidemics and famine).

Figure 1.5 Global Weather-Related Losses from "Great" Events: 1950-2005



Events are considered "great" if the affected region's resilience is clearly overstretched and supraregional or international assistance is required. As a rule, this is the case when there are thousands of fatalities, when hundreds of thousands of people are made homeless, or when economic losses — depending on the economic circumstances of the country concerned — and/or insured losses reach exceptional levels. Source: Munich Re, NatCatSERVICE.

From 1980 through 2004, the economic costs of "all"<sup>1</sup> weather-related natural disasters totaled US \$1.4 trillion (in 2004 US dollars) (Mills 2005), apportioned approximately 40/60 between wealthy and poor countries, respectively (Munich Re 2004).<sup>2,3</sup> To put the burden of these costs on insurers in contemporary perspective, the recent annual average is on a par with that experienced in the aftermath of 9/11 in the US.

The insured portion of losses from weather-related catastrophes is on the rise, increasing from a small fraction of the global total economic losses in the 1950s to 19% in the 1990s and 35% in 2004. The ratio has been rising twice as quickly in the US, with over 40% of the total disaster losses being insured in the 1990s (American Re 2005).

Where the burden of losses falls depends on geography, the type of risk and the political clout of those in harm's way. The developed world has sophisticated ways of spreading risk. While insurance covers 4% of total costs in low-income countries, the figure rises to 40% in high-income countries. A disproportionate amount of insurance payouts in high-income countries arise from storm events, largely because governments,

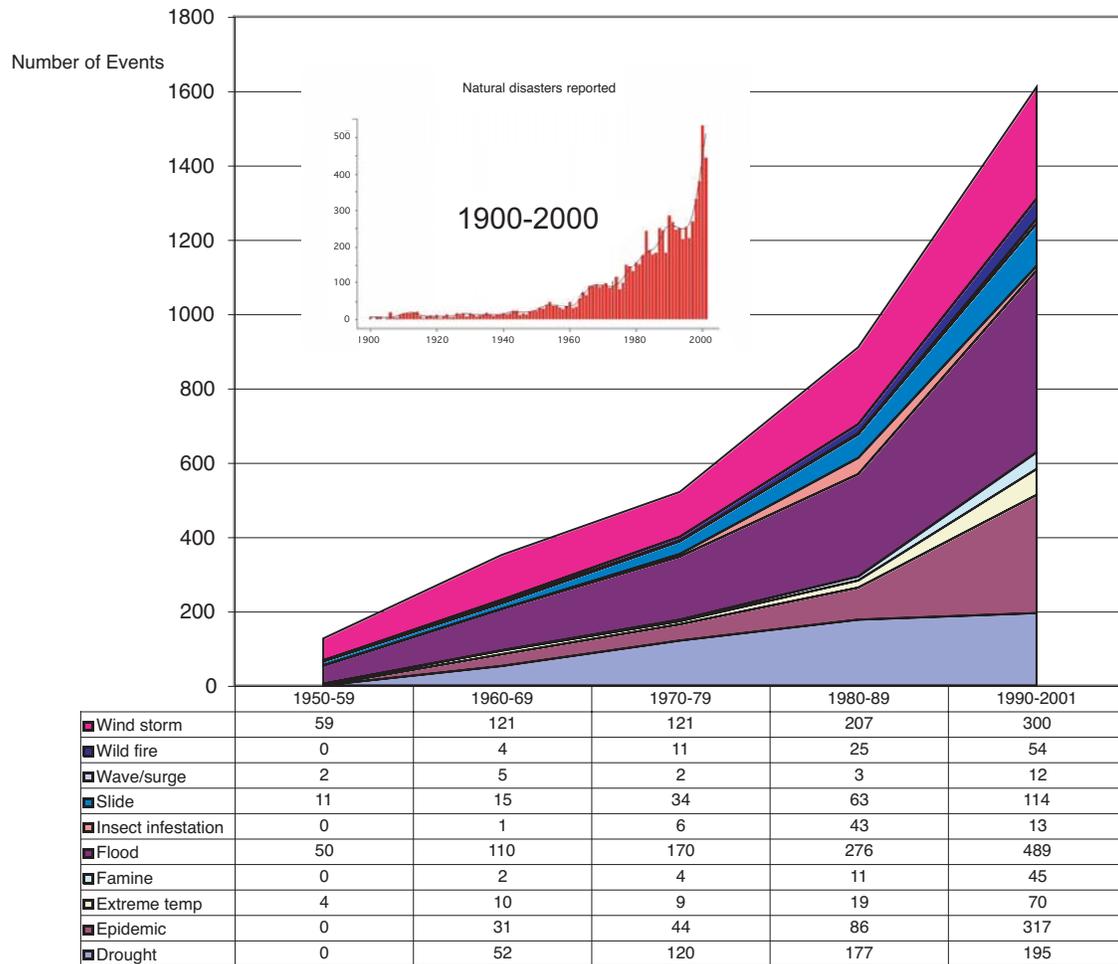
rather than the private sector, tend to insure flood rather than storm risk. In both rich and poor nations, economic costs (especially insured costs) fall predominantly on wealthier populations, whereas the loss of life falls predominantly on the poor.

1. This includes "large" and "small" events, as defined by insurers, but does not in fact fully capture all such events. For example, the Property Claims Service in the United States only counts events that result in over US \$25 million in insured losses.

2. Per Munich Re's definition, total economic losses are dominated by direct damages, defined as damage to fixed assets (including property or crops), capital, and inventories of finished and semifinished goods or raw materials that occur simultaneously or as a direct consequence of the natural phenomenon causing a disaster. The economic loss data can also include indirect or other secondary damages such as business interruptions or temporary relocation expenses for displaced households. More loosely related damages such as impacts on national GDP are not included.

3. Of 8,820 natural catastrophes analyzed worldwide during the period 1985-1999 (Munich Re 1999), 85% were weather-related, as were 75% of the economic losses and 87% of the insured losses.

Figure 1.6 The Frequency of Weather-Related Disasters



Growth and changing composition of natural disasters. Sources: OFDA / Center for Research in the Epidemiology of Disasters (CRED) "Natural.xls" Intl database of Disasters <http://www.em-dat.net> and US Census Bureau's International Database (<http://www.census.gov/ipc/www/idbagg.html>). From analysis completed by Padco's Climate Change Solutions Group for USAID's Global Climate Change Team.

With weather-related losses on the rise and extreme events more frequent, can we look back on historical data and draw conclusions about the likely impact of climate change on future losses? Can we tease out the role of climate from other factors when looking at specific events? The consequences are due to the combination of inflation, rising real estate values, the growth in coastal settlements and the increasing frequency and intensity of weather extremes (Vellinga et al. 2001; Kalkstein and Greene 1997; Epstein and McCarthy 2004; Egan 2005; Mills 2005; Emanuel 2005; Webster et al. 2005). As the return times for extremes grow shorter, the coping and recovery capacities are stretched thin, creating increasing vulnerability to further extremes even in the wealthiest nations.

Global data for floods show an upward trend in the number of events, fatalities and total economic losses. Some types of losses have grown particularly rapidly. Individual storms with damages exceeding US \$5 million grew significantly between the 1950s and the 1990s in the US (Easterling et al. 2000) — more rapidly than did population, housing values or overall economic growth.

Climate signals in rising costs from “natural” disasters are evident in many aspects of the data. Insurers observe a notable increase in losses during periods of elevated temperatures<sup>4</sup> and lightning strikes (predicted to rise with warming) (Price and Rind 1993, 1994a,b; Reeve and Toumi 1999) (see figure 3.6). Other factors, not captured by an overall examination of losses, point to an inherent bias toward underreporting the economic impact of climate extremes. The total losses are underestimates, since record-keeping systematically ignores relatively small events.<sup>5</sup> For example, smaller, often uncounted losses include those from soil subsidence or permafrost melt.

In the summer of 2005, for example, there were numerous areas of drought, flashfloods and wildfires that were barely accounted for.

While attention naturally focuses on headline-grabbing catastrophes, the majority (60%) of economic losses comes from smaller events (Mills 2005). In one recent example, a month of extremely cold weather in the northeastern US in 2004 resulted in US \$0.725 billion in insured losses (American Re 2005). The average annual insured loss from winter storms and thunderstorms is about US \$6 billion in the US, comparable to the loss from a significant hurricane (American Re 2005).

In addition, while the absolute magnitude of losses has been rising, the variability of losses has also been increasing in tandem with more variability in weather.

## LOSSES ARE SYSTEMATICALLY UNDERESTIMATED

The magnitude of losses presented in published data systematically underestimates the actual costs. For example:

Statistical bodies commonly create definitions that exclude from tabulation those events falling below a given threshold. For example, power outages in the

4. Data furnished by Richard Jones, Hartford Steam Boiler Insurance and Inspection Service (see figure 3.6)

5. For example, the insurance industry's Property Claim Services tabulated only those losses of US \$5 million or more up until 1996 and those of US \$25 million or more thereafter. As a result, no winter storms were included in the statistics for the 26-year period of 1949-1974, and few were thereafter (Kunkel et al. 1999). Although large in aggregate, highly diffuse losses due to structural damages from land subsidence would also rarely be captured in these statistics. Similarly, weather-related vehicular losses are typically not captured in the statistics.

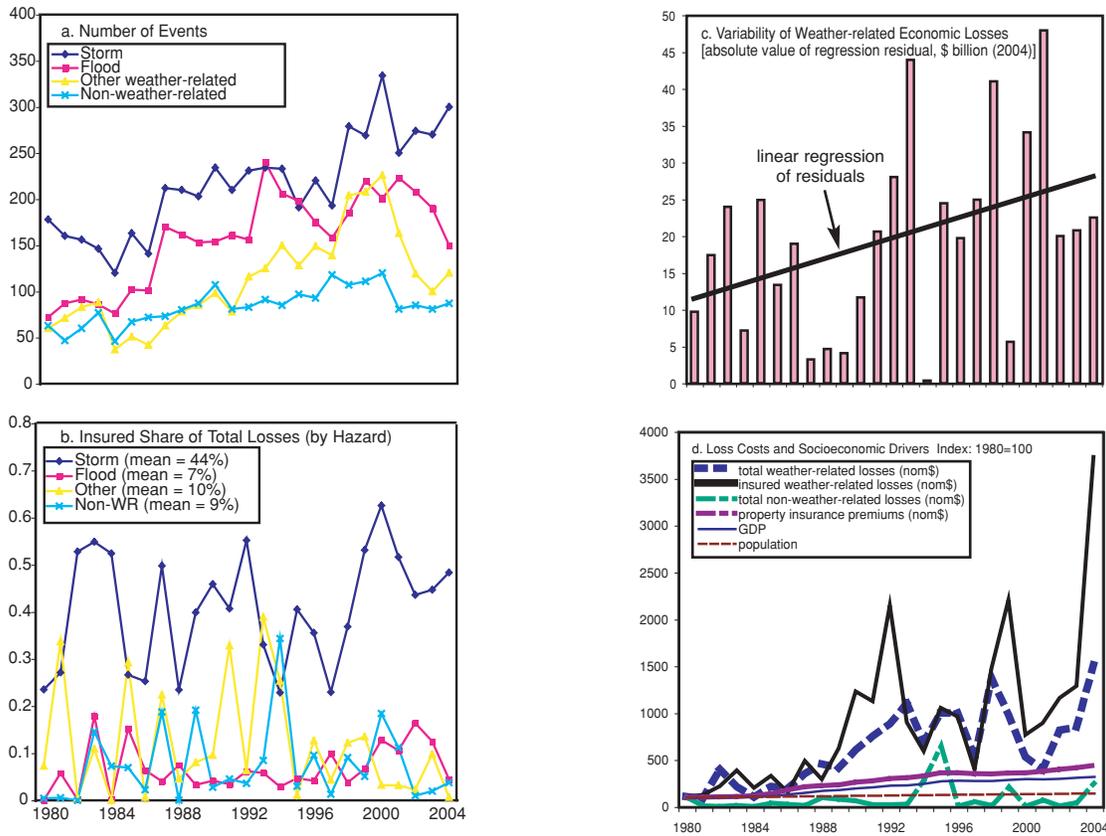
United States alone are estimated to result in a cost of US \$80 billion per year (LaCommare and Eto 2004), and weather-related events account for 60% of the customers affected by grid disturbances in the bulk power markets (see figure 1.8). Lightning strikes collectively result in billions of dollars of losses, as do damages to human infrastructure from soil subsidence (Nelson et al. 2001). Yet, such small-scale events are rarely if ever included in US insurance statistics due to the minimum event cost threshold of US \$5 million up to 1996, and US \$25 million thereafter. The published insurance figures reflect property losses and largely exclude the loss of life, and health costs (which are diffuse and rarely tabulated), business interruptions, restrictions on trade, travel and tourism, and potential market instability resulting from the health and ecological consequences of warming temperatures and severe weather.

The published data are not necessarily directly comparable with past data. For instance, in recent years, there has been a trend toward both increasing deductibles and decreasing limits, resulting in lower insurance payouts than had the rules been unchanged. Following Hurricane Andrew, insurers instituted special “wind” deductibles, in addition to the standard property deductible now in use in 18 US states plus Washington, DC (Green 2005a,b). Moreover, hurricane deductibles have moved toward a percentage of the total loss rather than the traditionally fixed formulation. The effect of such changes is substantial: for example, in Florida, 15 to 20% of the losses from the 2004 hurricanes were borne by consumers (Musulin and Rollins 2005).

These data also, of course, exclude the costs for disaster preparedness or adaptation to the rise in extreme weather events (flood preparedness, changes in construction practices and codes, improved fire suppression technology, cloud seeding, lightning protection, etc.). Insurance industry representatives reported that improved building codes helped reduce the losses of hurricanes in 2004 (Khanduri 2004).

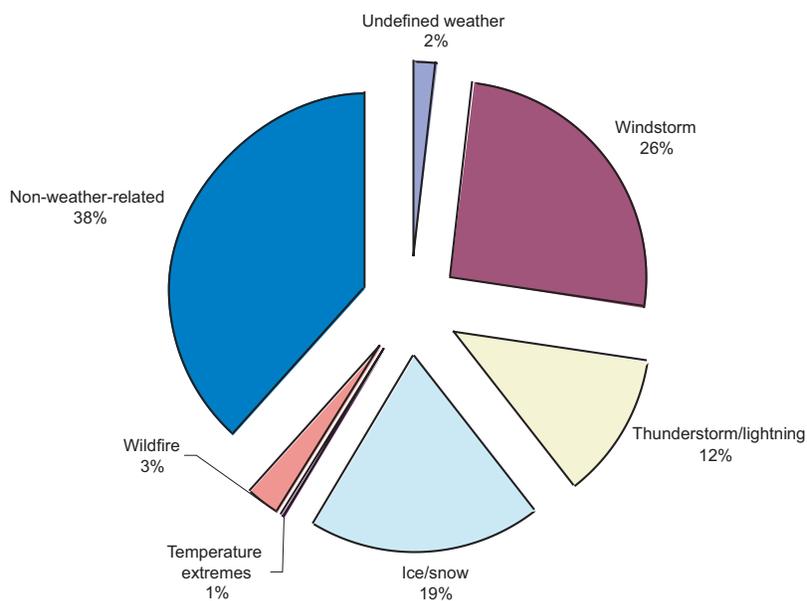
Other countervailing factors also mask part of the actual upward pressure on costs. Improved building codes, early warning systems, river channelization, cloud seeding and fire suppression all offset losses that might otherwise have occurred. Financial factors, such as insurer withdrawal from risky areas, higher deductibles and lower limits, also have a dampening effect on losses. All this means that the data do not necessarily reflect the increased costs to society of a changing climate.

Figure 1.7 Trends in Events, Losses and Variability: 1980-2004



Trends in numbers of events (a), insured share (b), variability of insured losses (c) and economic impacts (d). Global insured and total weather-related property losses (US \$45 billion and US \$107 billion in 2004, respectively) are rising faster than premiums, population or economic growth. Non-inflation-adjusted economic data are shown in relation to GDP. Data exclude health/life premiums and losses. Sources: Natural hazard statistics and losses from Munich Re, NatCatSERVICE, Premiums from Swiss Re, sigma as analyzed by Mills (2005).

Figure 1.8 Grid Failures From Weather and Other Causes: 1992-2002



Analysis of historical "Grid Disturbance" data from the North American Electric Reliability Council (<http://www.nerc.com/~filez/dawg-disturbancereports.html>). Data include disturbances that occur on the bulk electric systems in North America, including electric service interruptions, voltage reductions, acts of sabotage, unusual occurrences that can affect the reliability of the bulk electric systems, and fuel problems. NOTE: The vast majority of outages (80-90%) occur in the local distribution network and are not tabulated here. The sum of numbers is 101% owing to rounding.

## CLIMATE CHANGE CAN OCCUR ABRUPTLY

Perhaps the most daunting factor complicating the task of estimating the future health and economic impacts of climate change is that most climate futures and insurance industry projections drastically underestimate the rate at which climate might change.

Most envisioned climate futures of international assessments to date are based on gradual projections of increasing temperatures. Some include temperature variability, and others have begun to examine variance in weather patterns. But most do not reflect the high degree of variance in weather that is already occurring and few address the potential consequences of sudden change in impacts or abrupt shifts in climate itself.

The notion that climate might change suddenly, or shift from state to state, rather than change gradually — what Richard Alley calls the “switch” rather than the “dial” model for climate change — seemed like a radical notion when it first began to take hold in the early 1990s. In nature, however, sudden shifts are the rule, not the exception.

Steven J. Gould’s conception of evolution as “punctuated equilibrium” depicts long periods of relative stability with gradual change, punctuated by periods of mass extinctions. These “interruptions” are then followed by the explosion of new species with new solutions to new environmental problems that fit together into new communities of organisms.

On a more immediate time scale, non-linear changes are part of our daily experience. When temperatures change, liquid water can suddenly transform into a hard, latticed structure as it freezes or vaporizes, when it boils. Damage functions are also non-linear. For example, hailstones tend to bounce off of windshields until they reach a critical weight and break them.

Though abrupt climate change is a ubiquitous phenomenon and is observed throughout ice, pollen, fossil and geological records (NAS 2002), the bias toward gradual, incremental change may reflect the constraints of climate models that represent our best understanding of how dynamic systems behave. Models have a difficult time incorporating step-wise changes to new states. Most industries naturally base their projections

on linear extrapolations of past trends and current trajectories, though the insurance industry has long considered “catastrophe theory” to project the impacts of sudden, extreme losses. However, these models do not predict the probabilities of such events. For climate, increasing rates of change and greater volatility are signs of instability and suggest greater propensity for sudden change (Epstein and McCarthy 2004).

Even more challenging is the observation that changes in state can be triggered by small forces that approach (often unforeseen) thresholds or “tipping points” — and surpass them. Disease outbreaks can slowly grow in impact, for example, then suddenly become epidemics.

For the climate, the transitions between glacial and interglacial warm periods can involve changes from 5-10°C (9-18°F) in the span of a decade or less (Steffan et al. 2004b). Sudden shifts are sometimes restricted in geographic scope. At other times there are global transformations (Severinghaus et al. 1998; NAS 2002; Alley et al. 2003). Many such “high impact” events that were considered “low probability” just several years ago now seem to some increasingly likely (Epstein and McCarthy 2004) or inevitable (NAS 2002).

## TIPPING POINTS

### POSSIBLE “CLIMATE SHOCKS” WITH LIMITED GEOGRAPHIC IMPACTS

- Small sections of Greenland, the West Antarctic Ice Sheet (WAIS) or the Antarctic Peninsula could slip into the ocean, raising sea levels several inches to feet over years to several decades.
  - Meltwater is seeping down through crevasses in Greenland, lubricating the base of large glaciers (Krabill et al. 1999; ACIA 2005).
  - “Rivers of ice” in the WAIS are accelerating toward the Southern Ocean (Shepherd et al. 2001; Payne et al. 2004; Thomas et al. 2004).
  - Recent loss of floating ice shelves along the Antarctic Peninsula removes back pressure from the land-based ice sheets (Rignot and Thomas 2002).
- Alpine glacial melting could accelerate, inundating communities below and diminishing water supplies for nations dependent on this source for freshwater.

- Thawing of permafrost (permanently frozen land) could increase atmospheric concentrations of methane and contribute to further global warming.

- Methane, while shorter lived than CO<sub>2</sub>, is 21 times more powerful as a greenhouse gas.

## CANDIDATES FOR ABRUPT CLIMATE CHANGE

- Slippage of a large portion of Greenland or the WAIS would raise sea levels many feet, inundating coastal settlements throughout the world.
  - Loss of all of Greenland or the WAIS (unlikely to occur for centuries) would each raise sea levels 7 meters (21 feet).
- Release of methane from thawing Arctic and boreal permafrost could suddenly force the climate into a much warmer state (Stokstad 2004).
  - The world's largest frozen peat bog — a permafrost region the size of France and Germany combined, spanning the entire sub-Arctic region of western Siberia — has begun to melt for the first time since forming 11,000 years ago at the end of the last ice age (Pearce 2005). The Alaskan tundra is also thawing.
  - Western Siberia has warmed an average of 3°C (5.4°F) in the last 40 years, faster than almost anywhere else on Earth. The west Siberian bog contains some 70 billion tons of methane, a quarter of all the methane stored on the earth's land surface (Pearce 2005).
- Changes in the North Atlantic (ice melting and rain falling) could shut down the Gulf Stream and the ocean conveyor belt, triggering a "cold reversal" that alters climate in the Northern Hemisphere and the Middle East (NAS 2002; ACIA 2005).
  - The global impacts of such a shutdown might be tempered by overall global warming.
- There may be a threshold level or "tipping point" for Earth's total reflectivity (albedo).
  - The Earth's overall albedo is now about 30%. If enough ice melts and Earth's albedo decreases to 28%, for instance, the increased heat entering the oceans could potentially trigger a "runaway warming," with accelerated heating of Earth's surface. (Rignot and Thomas 2002; Rignot et al. 2004; Cook et al. 2005).

The instabilities underlying the potential "tipping points" are all present today — and they are not occurring in isolation. Several of the changes depicted could occur concurrently. Significant discharges of ice, for example, could be accompanied by large releases of methane. As modelers grapple with the potential for step-wise changes in the climate system (Schellnhuber 2002), the potential for multiple, linked abrupt changes to occur makes the outcomes and impacts of accelerated change all the more uncertain.

Management, adaptation and mitigation strategies that underestimate the potential for exponential change in biological systems or abrupt change in climate are unlikely to be successful. Substantially reducing greenhouse gas emissions to stabilize the concentrations could slow the rate of climate change and give the system the chance to reach a new equilibrium.

## THE CLIMATE CHANGE FUTURES SCENARIOS

In order to envision the future impacts of climate change, this study considers the potential for warming to proceed gradually, but with growing variance in weather. Both scenarios envision a climate context of gradual warming with growing variability and more weather extremes. Both scenarios are based on "business-as-usual," a scenario which, if unabated, would lead to doubling of CO<sub>2</sub> from pre-industrial values by midcentury. Extensive case studies described in Part II of this report provide background on the various classes of impacts. The first scenario calls for escalating impacts, and this assessment examines the economic dimensions of health and environmental impacts. The second scenario envisions a future with widespread, abrupt impacts. Note that these two scenarios are about the potential impacts of climate change, not the types of climate shocks or abrupt changes depicted above. The first scenario implies grave consequences for the global economy, while the widespread impacts of the second would be devastating and most likely unmanageable.

Regarding the worst-case scenario, the interested reader may refer to the "Pentagon Scenario" (Schwartz and Randall 2003) on abrupt climate change, which forces the reader to "think the unthinkable."

## CCF-I: GRADUAL WARMING WITH INCREASING VARIABILITY: ESCALATING IMPACTS

This baseline scenario explores an ensemble of conditions, events and impacts that have begun to appear in association with gradual anthropogenic climate change. Most of the outcomes envisioned in CCF-I are projections from current trends. As climate becomes more variable, weather extremes are projected to play an expanding role in the spread of disease and disturbance of ecological processes. In general, this scenario envisions the majority of events unfolding near the upper ranges of historical norms, in terms of intensity, duration and geographic extent.

In this scenario, thermal extremes and shifting weather patterns give rise to elevated rates of heat-related illness and more vector-borne disease. Increased volumes of dust swept vast distances, more photochemical smog and higher concentrations of CO<sub>2</sub>-linked aeroallergens (pollen and mold) drive up rates of asthma, which already afflicts one in six high school children in the US. CCF-I envisions a perceptible impairment of public health as a result of these ills, whether measured by morbidity and mortality, disability adjusted life years (DALYs) lost, or by the incremental medical resources devoted to the emerging problems and the associated rise in insurance costs. Ecological stress from warming, greater extremes and pest infestations would further undermine Earth's life-support systems and the public health benefits (Cifuentes et al. 2001) delivered by a healthy environment.

CCF-I would involve more frequent and intense heat waves. Lost productivity during hot months would become more routine and costly, and air-conditioning, thus electric power grid-capacity, would be stretched severely. Air quality issues would return to the front burner in the public eye as the extreme heat coupled with noxious air masses overwhelm pollution-abatement measures.

Floods would be more frequent and severe as well in the future envisaged in CCF-I. Some would be the result of storm surges in coastal areas, while others would result from an increased number of heavy precipitation events and overflowing rivers. The boundaries of floodplains could expand and more flooding, coupled with rising sea levels, would mean structures experience more moisture-related damage and drinking water systems become compromised more fre-

quently. Large numbers of people would suffer from water-related diseases.

The impacts on natural systems can directly and indirectly affect human health. Agricultural diseases and extreme events that hamper food production affect nutrition. CCF-I envisions steady increases in pests that harm important crops, with less food of lower quality being produced at a higher cost. Animal and livestock diseases may also increase, and some may jump to humans.

Maintaining biodiversity of plants and animals is key to preserving forest health (Daszak et al. 2000). Even gradual climate change, however, can produce a surge of forest pests and eliminate "keystone" species that perform essential functions. Loss of forested tracts to drought and pests would lead to more wildfires, causing deaths, injuries and extensive property damage. The human losses associated with fire fighting in forested areas would increase, as would respiratory disease regionally.

Coral bleaching and diseases of coral reefs would accelerate in CCF-I. This oldest of Earth's ecosystems provides multiple and some irreplaceable services: as a buffer from storm surges, as nurseries for many fish, and as a source of income through tourism. The potential fate of coral around the globe — when already 60% of reefs are threatened — serves as a grim illustration of the potential ecological and economic consequences of losing essential habitat. For the insurance industry, weather-related property losses and business interruptions would continue to rise at rates observed through the latter 20th century and the beginning of the 21st. The insured share of these losses would increase, as more developed areas are affected, and underwriting becomes more problematic. This places stress on the solvency of some insurance companies and even affects the strongest firms. In this scenario, climate-change effects are a risk that has emerged.

Corporations face more environmentally related litigation (and associated insurance payouts), both as emitters of greenhouse gases and from non-compliance with new regulations in a changed political climate in which public alarm mounts. Climate impacts begin to have a more noticeable effect on insured lives, a new development for the life/health branch of the insurance industry. Epidemics and extremes impair the "climate of investment" in some regions and affect financial services and investment portfolios. In sum, the insurance industry and investors would face accelerating trends that weaken returns and profitability.

## CCF-II: GRADUAL WARMING WITH INCREASING VARIABILITY: SURPRISE IMPACTS

Even within the conditions of climate change underlying the first impact scenario — gradual warming and increasing variance — there is the possibility of sudden and catastrophic impacts on health, ecosystems and economies. Widespread epidemics, explosive crop and forest infestations, and coral reef collapse could severely damage the social fabric.

Note again: This is not a scenario of abrupt change in the physical climate system; it is a scenario of surprises and widespread impacts due to growing instability in climate. The effects of “climate shocks” and potential triggers for abrupt climate change outlined above extend far beyond these impact scenarios, and the implications of such major transformations in the global climate system are too vast as to be considered in monetary terms.

In this scenario of non-linear impacts, disruptions would be greater and the economic costs of natural catastrophes would rise abruptly. Recurrent devastating storms would render current adaptation methods less effective and more costly. With non-linear impacts appearing in many regions simultaneously, the ability of business, governments and international organizations to respond would become critically taxed. This scenario would be more challenging for insurers and other risk managers due to increasing uncertainty.

Extreme heat catastrophes become more common and widespread in CCF-II. Events on a par with that seen in Europe in the summer of 2003 affect many parts of the globe. Temperature records are broken in numerous megacities as they are subjected to oppressive and unhealthy air masses. Heat-related morbidity and mortality rise from 200% to 500% above long-term averages. The potential decrease in winter illnesses is negated by increasing variability of temperatures (Braga et al. 2001) and more sudden cold spells, plus rain, snow and ice storms. Winter travel and ambulation become extremely hazardous during some years (EPA 2001).

The increase in epidemics of infectious diseases, especially following disasters, strain existing health care and public health infrastructure, halting or reversing economic growth in some underdeveloped nations. More frequent disease outbreaks also take a

toll on productivity, tourism, trade and travel, crippling the climate of investment in “emerging markets” and the availability of insurance in some sectors.

Air quality deteriorates. The combination of rising pollen and soil mold counts from CO<sub>2</sub>-fertilization; greater heat, humidity and particulate-filled hazes; smog and oppressive nights; respiratory irritants from widespread summer fires; and dust clouds transported from expanding deserts exacerbates upper and lower airway disease and cardiovascular conditions (Griffen et al. 2001).

The changing climate alters the prevalence and spatial extent of crop pests and diseases around the globe. Populations of insect herbivores like locust explode in some regions — as they did in northern Africa and southern Europe in the summer of 2004 — greatly decreasing crop yields. Increased CO<sub>2</sub> contributes to more vigorous weed growth and the worldwide crop losses today attributed to pests, pathogens and weeds increases from the current 42% (Altaman 1993; Pimentel and Bashore 1998) to over 50% of potential yields. Crop damage from drought, storms, floods and extreme heat episodes compound the disease-related losses. Yields are decimated in some regions, leading to widespread famine, debilitating epidemics and political instability.

Looming in such a scenario is the potential for a rapid, widespread climate- and disease-induced dieback of forests. The combination of multi-year droughts; warm, dry winters leaving little mountain snowpack; and an explosion of pests, such as bark beetles, leaf miners, opportunistic fungi and aphids affecting weakened trees, would create vast dead stands that provide fuel for wide-scale fires. Such massive losses of forest cover and transformations of terrestrial habitat would send reverberations through nature and human society, affecting birds and other wildlife, lumber and water quality and availability. As a final insult, widespread fires in these increasingly flammable forests would release large carbon pulses, adding to global warming and altering forest soils that provide an essential “sink” for storing carbon.

Finally, coral reefs weaken (physically and biologically). Surface ocean warming and disease compound the stress on the reefs already generated by overfishing, and by human and industrial waste. Most of the globe’s tropical ring of reefs collapses, while sea level rise and higher storm and tidal surges inundate coastal

communities, salinizing ground water and under-island freshwater lenses (the pocket of fresh water underlying inhabitable islands), which affects agriculture, human health and habitability.

The compounding effects of such massive and concurrent losses become visible in many lines of the insurance business. As a result, insurers withdraw from segments in a variety of markets, particularly coastlines and shores vulnerable to sea level rise and loss of barrier habitat. Contraction by insurers has a dampening effect on economic activity.

In the largely uninsured developing world, climate change impacts displace large populations, putting great stress on the nations receiving the exodus. Social instability also triggers “political risk” insurance systems that insure against expropriation or nationalization of assets or losses resulting from politically motivated violence, such as civil or cross-boundary conflict.

Meanwhile, insurance companies have difficulty raising deductibles commensurate with the losses and adopting adequate loss limits, effectively deeming certain events uninsurable and thus shifting a share of the losses back to individuals or governments (Mills et al. 2005). In cases where commercial insurance is no longer available, already beleaguered public insurance systems attempt to fill the void, but many nations find it increasingly difficult to absorb the costs.

Part II of this report delves into case studies of health conditions and extreme weather events underpinning these two potential futures.

**PART II:**  
*Case Studies*

*Health is the final common pathway of the natural systems we are part of, and climate instability is altering the patterns of disease and the quality of our air, food and water. The following case studies integrate the multiple dimensions of diseases whose range and prevalence are affected by climate. The studies are approached from the perspective of a disease or condition (for example, malaria and asthma), a meteorological event (for example, a heat wave and flood) or from the view of natural and managed Earth systems (agriculture, forests, marine and water). The cases are organized according to background, the role of climate, health and ecological impacts, economic dimensions, scenario projections and specific recommendations to reduce vulnerabilities.*

*Primary prevention for all the illnesses and events addressed include measures to stabilize the climate.*

## INFECTIOUS AND RESPIRATORY DISEASES



### MALARIA

Kristie L. Ebi  
Nathan Chan  
Avaleigh Milne  
Ulisses E. C. Confalonieri

### BACKGROUND

Malaria is the most disabling vector-borne disease globally and ranks number one in terms of morbidity, mortality and lost productivity. Some 40% of the world's population is at risk of contracting malaria, and roughly 75% of cases occur in Africa, with the remainder occurring in Southeast Asia, the western Pacific and the Americas (Snow et al. 2005). Up to 75% of cases occur in children, and over 3,000 children die from malaria each day (WHO 2003).

*Plasmodium falciparum* is one of four types of malaria and is responsible for the majority of deaths. While advances in antimalarial drugs and insecticides in the first half of the 20th century led to the optimistic view that malaria could be eradicated, widespread drug and pesticide resistance, and the subsequent failure of control programs, proved this optimistic view wrong and the world is currently experiencing an upsurge in malaria.

The three facets of this case study examine the impacts of flooding on malaria in Mozambique, the indirect impacts of drought on malaria distribution in northeast Brazil, and the projected impacts of warming and altered precipitation patterns affecting the potential range of malaria in the highlands of Zimbabwe. These studies serve as examples of how warming and weather

extremes can work alone and in combination to influence the prevalence and dynamics of a tropical vector-borne disease, and, by extrapolation, how changes may occur in temperate regions at the margins of malaria's current distribution.

### THE ROLE OF CLIMATE

Climate constrains the range of malaria transmission while floods (and sometimes droughts) provide the conditions for large outbreaks. Warming, within the viable range of the mosquito (too much heat kills them), boosts biting and reproductive rates, prolongs breeding seasons and shortens the maturation of microbes within mosquitoes.

For malaria transmission to occur, a mosquito must take a blood meal from someone with malaria, incubate the parasite, then bite an uninfected person and inject the parasite. Warmer temperatures speed up the maturation of the malarial parasites inside the mosquitoes. At 20°C (68°F), for example, *Plasmodium falciparum* malarial protozoa take 26 days to incubate; but, at 25°C (77°F), the parasites develop in half the time (McArthur 1972). Anopheline mosquitoes that can transmit malaria live only several weeks. Thus warmer temperatures permit parasites to mature in time for the mosquito to pass it on to someone previously uninfected.

Malaria is circulating among populations living at low altitudes and increasingly in highland areas in Africa. Heavy rains create mosquito breeding sites along roadways and in receptacles (though flooding can sometimes have the opposite effect, washing mosquito eggs away). Droughts can lead to upsurges of malaria via another mechanism: encouraging the migration of human populations into (or out of) malarious areas.

Climate change is compounding other changes influencing the distribution of malaria. Population migrations, deforestation, drug and pesticide resistance also contribute and public health infrastructure has deteriorated in many countries (Githeko and Ndegwa 2001; Greenwood and Mutabingwa 2002). But, as climate changes, warming and weather extremes are likely to play expanding roles in the spread of malaria (McMichael et al. 2002).

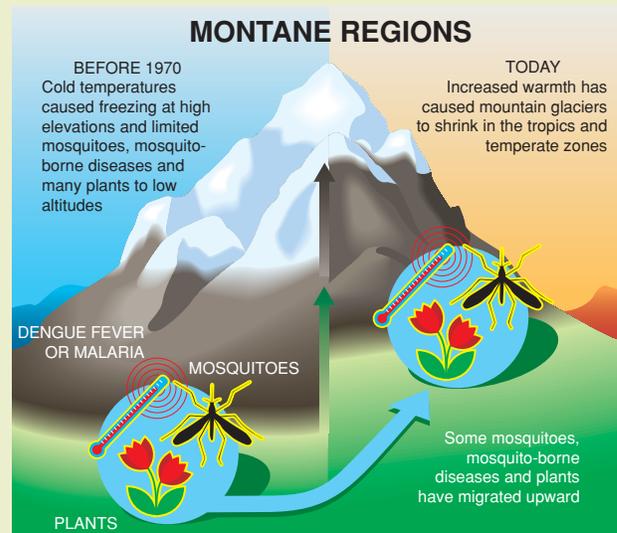
# CLIMATE CHANGE AND EMERGING INFECTIOUS DISEASES

Microbes and other living organisms tend to increase their numbers exponentially; their population levels reflecting environmental conditions and resource constraints. Historically, periods of social and environmental transition have been accompanied by waves of epidemics spanning multiple continents (Epstein 1992). Changes in the timing of seasons and greater weather variability can destabilize natural biological controls over opportunistic organisms.

Ecological instabilities play key roles in the emergence of diseases and the resurgence of old scourges (IOM 1992). Predators are needed to control prey and prevent them from becoming pests (Epstein et al. 1997), while competitors that are poor carriers of pathogens may “dilute” them and decrease transmission (LoGiudice et al. 2003). Species extinctions may play an insidious role because of the loss of functions they perform in controlling the proliferation of opportunistic organisms. Background ecological changes today are profound: we are using Earth’s resources and generating wastes at a rapid pace (Wackernagel et al. 2002) and the Millennium Ecosystem Assessment (2005) found that 60% of ecosystem resources and services are being used unsustainably (Mooney et al. 2005). Today 12% of birds, 23% of mammals, 25% of conifers and 32% of amphibians are threatened with extinction and the world’s fish stocks have been reduced by 90% since the 1850s. Following mass extinctions, opportunistic species can flourish until new communities of organisms are established.

The resurgence of old diseases, such as malaria and cholera, the redistribution of still others (like West Nile virus) and the emergence of new diseases are of considerable concern. Since the late 1990s, the pace of new and resurgent infections appearing in humans, animals and plants has continued unabated (Epstein et al. 2003). Persistent poverty and deteriorating public health programs underlie the rebound of most diseases transmitted “person-to-person” (for example, diphtheria and tuberculosis).

Figure 2.1



*In highland regions in Africa, Central and South America, and Asia plant communities are migrating upward, glaciers are retreating and mosquitoes are being found at high elevations. Underlying these changes are higher temperatures (an upward shift of the freezing isotherm) and thawing of permafrost (permanently frozen ground). Image: Bryan Christie/Scientific American August 2000*

From 1976 to 1996, the World Health Organization (1996) reports the emergence of over 30 diseases “new” to medicine, including HIV/AIDS, Ebola, Lyme disease, Legionnaires’, toxic *E. coli* and a new hantavirus; along with a rash of rapidly evolving antibiotic-resistant organisms. But the resurgence and redistribution of infections involving animal vectors, hosts and reservoirs — mosquitoes, ticks, deer, birds and rodents — reflect changing ecological balances and an altered climate (Epstein 2005).

## Range Changes: Focus on Highland Regions

The geographic distribution and activity of insects are exquisitely sensitive to temperature changes. Today, insects and insect-borne diseases are being reported at high elevations in East and Central Africa, Latin America and Asia. Malaria is circulating in highland urban centers, such as Nairobi, and rural highland regions, like those of Papua New Guinea. *Aedes aegypti*, the mosquito carrier of dengue and yellow fever, has been limited by temperature to about 1,000m (3,300 ft) in elevation. In the past three decades it has been found at 1,700m (5,610 ft) elevation in Mexico and 2,200m (7,260 ft) in the Colombian Andes (Epstein et al. 1998).

Measurements drawn from released weather balloons, satellites and ground thermometers all show that mountain regions are getting warmer. Between 1970 and 1990 the height of the freezing isotherm (permafrost or permanently frozen ground) climbed approximately 160m (almost 500 feet) within the tropics, equivalent to almost 1°C (1.8°F) warming (Diaz and Graham 1996). Exemplifying this trend, plants are migrating to higher elevations in the European Alps, Alaska, the US Sierra Nevada and New Zealand (Pauli et al. 1996). These insect and botanical trends, indicative of gradual, systemic warming, have been accompanied by the accelerating retreat of summit glaciers in Argentina, Peru, Alaska, Iceland, Norway, the Swiss Alps, Kenya, the Himalayas, Indonesia, Irian Jaya and New Zealand (Thompson et al. 1993; Mosley-Thompson 1997; Irion 2001).

### Extreme Weather Events and Epidemics

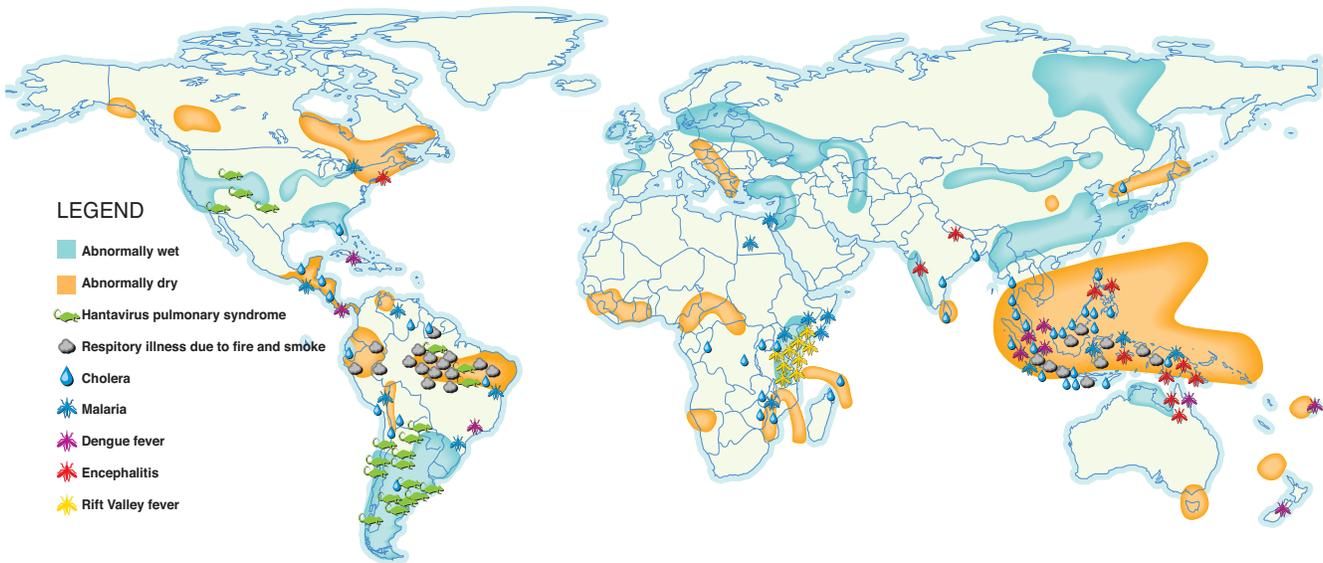
Extreme weather events are having even more profound impacts on public health than the warming itself (Bouma et al. 1997; Checkley et al. 1997; Kovats et al. 1999). Prolonged droughts fuel fires, releasing respiratory pollutants, while floods can create mosquito-breeding sites, foster fungal growth (Dearborn et al. 1999), and flush microbes, nutrients and chemicals

into bays and estuaries, causing water-borne disease outbreaks from organisms like *E. coli* and *cryptosporidium* (Mackenzie et al. 1994).

Infectious diseases often come in groups or “clusters” in the wake of extreme weather events. Hurricane Mitch — nourished by a warmed Caribbean — stalled over Central America in November 1998 for three days, dumping six feet of rain that killed over 11,000 people and left over US \$5 billion in damages. In the aftermath, Honduras reported 30,000 cases of cholera, 30,000 cases of malaria and 1,000 cases of dengue fever (Epstein 2000). The following year, Venezuela suffered a similar fate, followed by outbreaks of malaria, dengue fever and Venezuelan equine encephalitis. In February 2000, torrential rains and a cyclone inundated large parts of Southern Africa and the floods in Mozambique killed hundreds, displaced hundreds of thousands and spread malaria, typhoid and cholera (Pascual et al. 2000). When three feet of rain fell on Mumbai (Bombay), India, on July 26, 2005, the flooding unleashed epidemics of mosquito-borne diseases (malaria and dengue fever), water-borne diseases (cholera and other diarrheas) and a rodent carried and water-borne bacterial disease (leptospirosis, which can cause meningitis, kidney disease and liver failure).

– P.E.

Figure 2.2 Extreme Weather Events and Disease Outbreaks: 1997-1998



Outbreaks of infectious diseases carried by mosquitoes, rodents and water often “cluster” following storms and floods. Droughts also lead to water-borne diseases and disease from fires. The events above occurred in 1997-1998, during the century’s largest El Niño.  
Image: Bryan Christie/Scientific American August 2000

## HEALTH IMPACTS

Malaria is characterized by intense fever, sweats and shaking chills, followed by extreme weakness. Chronic states of infection exist for most forms of malaria, producing anemia, periodic fevers and often chronic disability. *Plasmodium falciparum* is the most lethal form of malaria and is the main parasite circulating in Africa. There is evidence that shifts in the types of malaria are occurring in some nations, with a growing percentage of mosquitoes carrying *P. falciparum* in Venezuela and Sri Lanka (Y. Rubio; F. Amerasinghe, pers. comm. 2002).

Previous estimates from the World Health Organization state that 300-500 million cases of malaria occur worldwide every year and estimates of annual deaths

range from one to three million (Sachs et al. 2001; WHO 2001). The true impact on mortality may be double these figures if the indirect effects of malaria are included. These include malaria-related anemia, hypoglycemia (low blood sugar), respiratory distress and low birth weight (Bremam 2001).

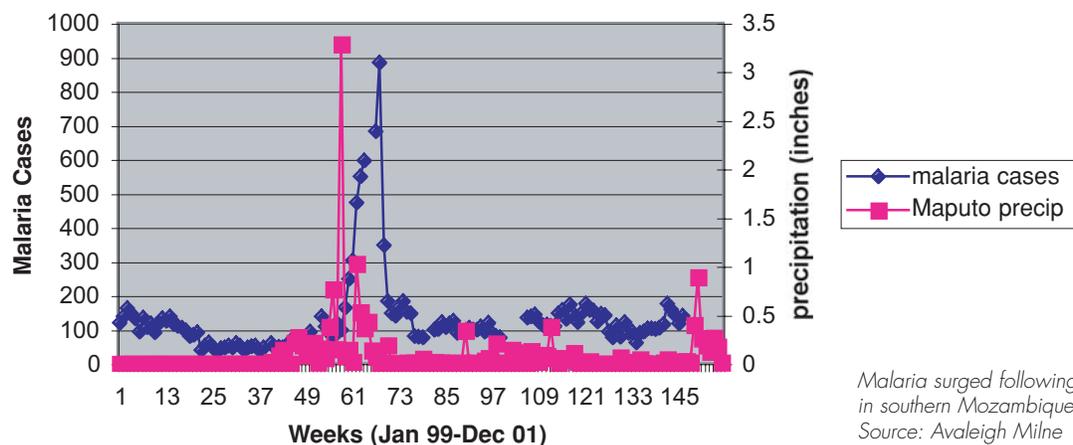
Approximately 11% of all years of life lost across sub-Saharan Africa are due to malaria (Murray and Lopez 1996) and a study in 2002 suggests that the *falciparum* parasite caused 515 million cases of malaria that year (Snow et al. 2005). In sub-Saharan Africa, malaria remains the most common parasitic disease and is the main cause of morbidity and mortality among children under five and among pregnant women (Freeman 1995; Blair Research Institute 1996).

Figure 2.3 Debilitated man suffering from malaria



Image: Pierre Viot/WHO

Figure 2.4 Malaria and Floods in Mozambique



*Malaria surged following six weeks of flooding in southern Mozambique.*

*Source: Avaleigh Milne*

## FLOODING IN MOZAMBIQUE

In February and March of 2000, Mozambique experienced a devastating series of three tropical cyclones and heavy rains over a six-week period. Hundreds of people were killed directly from drowning and hundreds of thousands were displaced by the area's worst flooding on record. The post-flood propagation of mosquitoes, coupled with increased risk factors among the population (including malnutrition and destroyed houses and infrastructure) led to a malaria epidemic. Washed-out roads and bridges impeded emergency relief and access to care.

In southern Mozambique, the area hit hardest by the floods of 2000, records from regional health posts and district hospitals before and during the flooding demonstrated the impacts. Daily precipitation and maximum temperatures from two regional observation stations — Maputo (the capital) and Xai-Xai — showed a four-to-five fold spike in malaria cases following the flooding, compared with otherwise relatively stable levels over three years (see figure 2.4).

## DROUGHT IN BRAZIL

Three centuries of sugar plantations in northeast Brazil drained water from the region's aquifers to send as rum across the Atlantic to fuel the "triangular trade." The altered microclimate and recurrent drought has left the region impoverished. Recurrent crop failures and hunger has driven job-seeking migration from rural to urban areas, bringing with it a cohort of humans carrying malaria (Confalonieri 2003). Sometimes uninfected migrants move into heavily infected areas in the Amazon and return to their home regions with heavy burdens of disease.

During the El Niño-related intensified droughts of the 1980s and 1990s, many inhabitants of the state of Maranhão migrated to the neighboring Amazon region, which has a high rate of malaria. As the drought abated, migrants returned to their homelands, causing a sharp rise in imported malaria.

## PROJECTIONS FOR ZIMBABWE

Roughly 45% of the population of Zimbabwe is currently at risk for malaria (Freeman 1995). A variety of model projections of the impacts of climate change on the range and intensity of malaria transmission have shown that changes in temperature and precipitation could alter the transmission of malaria, with previously unsuitable areas of dense human population becoming suitable for transmission (Lindsay and Martens 1998; Martens et al. 1999; Rogers and Randolph 2000). Despite using different methods and reporting different results, the various models reach similar conclusions: The future spread of malaria is likely to occur at the edges of its geographical distribution where current climate limits transmission.

Notably all these analyses are based upon projected changes in average temperatures, rather than the more rapid increase in minimum temperatures being observed; and thus may underestimate the actual biological responses.

## ECONOMIC DIMENSIONS

Good population health is critical to poverty reduction and long-term economic development. Malaria reduces the lifetime incomes of individuals, national incomes and prospects for economic growth. With

Figure 2.5 Brazil



Recurrent drought in northeast Brazil has caused mass migrations into malarious areas in the Amazon. Image: maps.com

inadequate medical and economic infrastructures, disease management is difficult, contributing to a vicious circle that hinders development.

In sub-Saharan Africa in 1999, malaria accounted for an estimated 36 million lost Daily Adjusted Life Years (Murray and Lopez 1996). (DALYs are the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability.) If each DALY is valued as equal to per capita income, the total cost of malaria would be valued at 5.8% of the GNP of the region. If each DALY is valued at three times the per capita income, the total cost would be 17.4% of GNP.

Just as a country's GDP influences malaria risk, malaria has been shown to decrease economic growth in severely malarious countries by 1.3 growth rate percentage points per year (Gallup and Sachs 2001; WHO 2001). The economic development necessary for improvements in the public health infrastructure is directly hindered by the presence of malaria itself. Changes in climate have the potential to make it even more difficult for poor countries to reduce the burden of malaria.

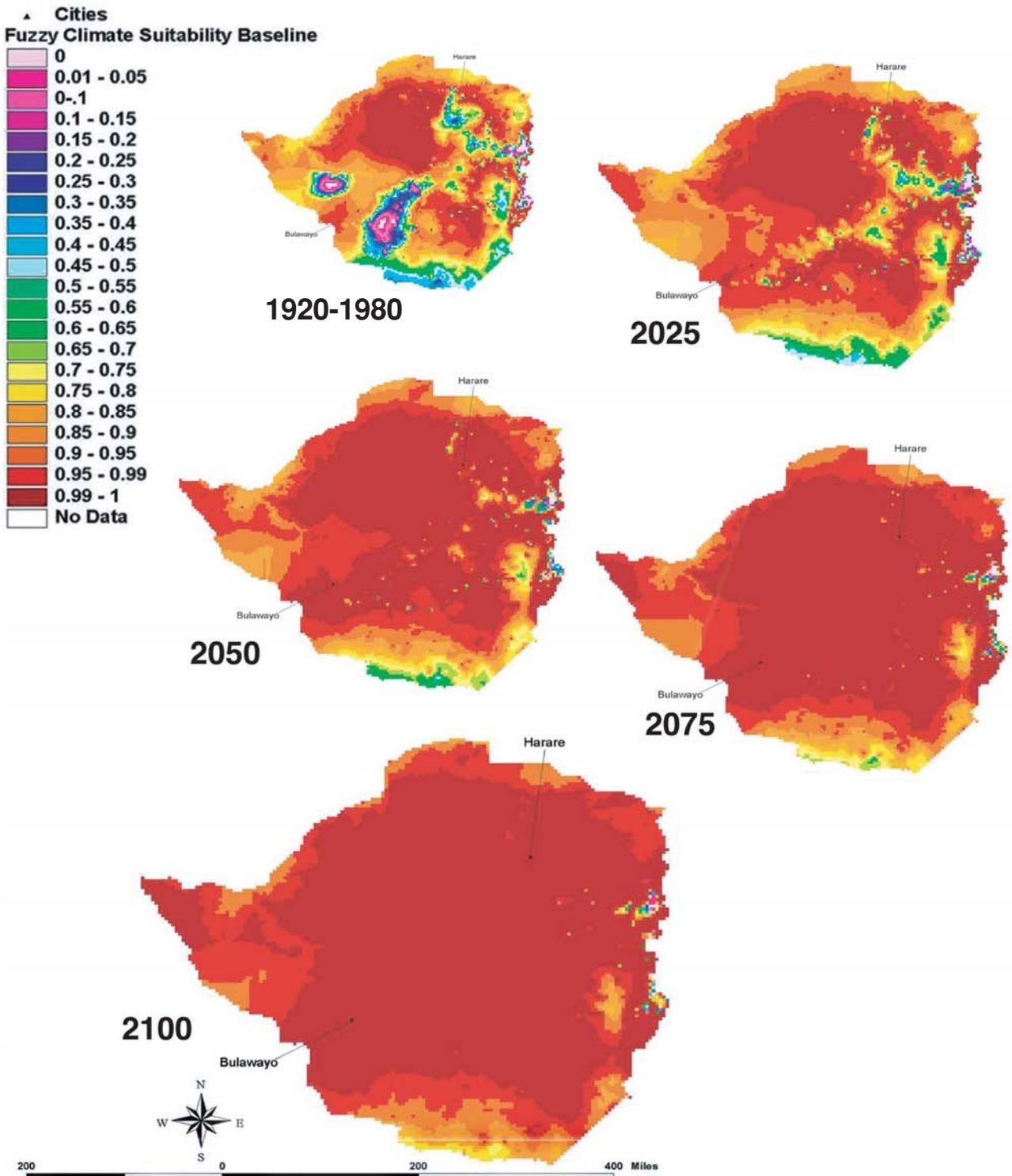
Although most studies of the economic burden of disease look only at the costs associated directly with an episode of illness, non-fatal illness early in life can have adverse economic consequences throughout one's life. Disease in infancy and in utero can be associated with lifetime infirmities. In addition, disease of one individual within the family may have important adverse consequences for other family members, especially the other children.

Malaria also poses risks to tourists and to military personnel, can inhibit the use of arable land and access to natural resources, and can present an impediment to international investment.

The cost of improving malaria activities is great. National expenditures on such public goods as vector control, health-care delivery and infrastructure, disease surveillance, public education, and basic malaria research are limited by a country's GDP. According to the World Health Organization, only 4% of the population at risk from malaria transmission in Sub-Saharan Africa are currently using insecticide-impregnated bed nets and household insecticide-spraying for malaria prevention, and only 27% of people with malaria receive treatment. Overall incremental expenditure

Figure 2.6

## Climate Suitability for Stable Malaria Transmission in Zimbabwe



These simulations show how the regions suitable for transmission of malaria move up in altitude with changes in temperature and precipitation.  
Source: Springer Science and Business Media

estimates (over and above current annual health expenditure) to reach 40% coverage for prevention and 50% for treatment (projected 2007 goals) are US \$0.65-1.4 billion for prevention and US \$0.6 billion to US \$1.1 billion for treatment. Reaching the 2015 Millennium Development Goals of 70% prevention coverage and 70% treatment would require increased annual expenditure of US \$1.45-3.2 billion for prevention and US \$1.4-2.5 billion for treatment activities. WHO's Roll-Back Malaria and the Global Fund to Fight AIDS, Tuberculosis and Malaria are among the new international programs dedicated to addressing this resurgence.

Widespread drug resistance and lack of resources and infrastructure for prevention and treatment methods contribute to the high incidence of malaria in Mozambique and Zimbabwe and in many other nations. The cost of medications (US \$1-3 per treatment) and bed nets (US \$5) must be viewed in context, for the total government health expenditures per capita is US \$6 in Mozambique and even less in many other countries.

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Projected changes include the expansion of conditions that support the transmission of malaria in latitude and altitude and, in some regions, a longer season during which malaria may circulate (Tanser et al. 2003; van Lieshout et al. 2004). Ethiopia, Zimbabwe, and South Africa are projected to show increases of more than 100% in person-months of exposure later in this century, changes that could dramatically increase the burden of those suffering with malaria.

The potential future geographic distributions of malaria in Zimbabwe were calculated using 16 projections for climate in 2100 (Ebi et al. *in press*). The results suggest that changes in temperature and precipitation could alter the geographic distribution of malaria in Zimbabwe; previously unsuitable areas with high population densities — especially in the now-hospitable highlands — would become suitable for transmission. The low-lying savannah and areas with little precipitation show varying degrees of change. More intense precipitation events and floods are also projected in sub-Saharan Africa and these events are expected to precipitate large outbreaks.

For Brazil, more intense droughts are projected for the Northeast region due to warming and continued deforestation in the Amazon. This will increase migration and the transmission of malaria.

Under CCF-I, therefore, we can anticipate an increase in the global burden of malaria and mounting adverse impacts on families, school attendance and performance, productivity and the 'climate' for investment, travel and tourism. Poor nations with low GNPs will face the heaviest burdens, devoting more and more of their precarious resources to combating this disease. The per capita losses in Disability Adjusted Life Years are projected to increase substantially. In developed nations, locally transmitted outbreaks of malaria increase, necessitating increased use of pesticides, which carry their own long-term health threats via contamination of water and food.

### CCF-II: SURPRISE IMPACTS

Under CCF-II we project intensification of malaria transmission throughout highland regions in Africa, Latin America and Asia, with continued transmission in lowland regions. In addition, malaria could suddenly swell in developed nations, especially in those areas now bordering the margins of current transmission. This could present severe problems in southern regions of Western and Eastern Europe and in the southern US. The impact measured in DALYs would be substantial if malaria returns to parts of the developed world. The strains on public health systems and on health insurance would come at a time when warming and the intensified hydrological cycle are increasing the overall burden of disease due to infectious agents. The increasing use of medicines for treatment and chemicals for mosquito control would exacerbate drug and insecticide resistance, boosting the costs of the disease and the costs of disease control. If the current methods for combating malaria lose their efficacy as a result of overuse of these chemical agents, the potential spread of malaria in a step-wise fashion would pose severe threats to human health as well as to economic development. This would be one of the dangerous interactions envisaged in CCF-II, in which a non-linear change has an unpredictable cascading effect on society and social development.

# A MALARIA SUCCESS

The New York Times, 27 March 2005

In 1998, the Australia-based mining company BHP Billiton began building a huge aluminum smelter outside Maputo, the capital of Mozambique. The company knew that malaria plagued the region. It gave all its workers mosquito nets and free medicine, and sprayed the construction site and workers' houses with insecticide. Nevertheless, during the first two years of construction there were 6,000 cases of malaria, and at least 13 contractors died.

To deal with the problem, the company did something extraordinary. It joined an effort by South Africa, Mozambique and Swaziland to eradicate malaria in a swath of the three countries measuring more than 40,000 square miles. The project is called the Lubombo Spatial Development Initiative, after the mountains that define the region. In the three years since house-to-house insecticide spraying, surveillance and state-of-the-art treatment began, malaria incidence dropped in one South African province by 96 percent. In the area around the aluminum smelter, 76 percent fewer children now carry the malaria parasite. The Lubombo initiative is probably the best antimalaria program in the world, an example for other countries that rolling back malaria is possible and cost-effective.

In its first years, financing came from BHP Billiton and the Business Trust, a development organization in South Africa financed by more than 100 companies there. They decided to fight malaria not only to save children and improve health, but also to encourage tourism and foreign investment. Governments should make the same calculation, and should follow the Lubombo example. Malaria kills some two million people a year, nearly all of them children under 5. A commission of the World Health Organization found that malaria shrinks the economy by 20 percent over 15 years in countries where it is most endemic.

The Lubombo initiative hires and trains local workers, who spray houses with insecticide once or twice a year, covering their communities on foot. People who get malaria are cured with a new combination of drugs that costs about USD 1.40 per cure for adults, abandoning the commonly used medicines that cost only pennies but have lost their effectiveness. While it is still the largest antimalaria project started by business in Africa, there are other successful ones, run by Marathon Oil, Exxon Mobil and the Konkola copper mines in Zambia. Fifty years ago, Africa did use house spraying widely, with good results, but such projects vanished as the money dried up. Today money is available again, from the Global Fund to Fight AIDS, Tuberculosis and Malaria, and the Lubombo initiative's managers are beginning to get calls from other parts of Africa. Malaria, unlike many other diseases, is entirely preventable and curable. The challenge for health officials is to fight malaria in very poor countries on a large scale, and now they have the Lubombo initiative to show them how.

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## SPECIFIC RECOMMENDATIONS

Preventing deforestation is the most significant environmental intervention for limiting the spread of malaria. Deforested areas are prone to flooding and habitat fragmentation increases mosquito-breeding sites, while removing habitat for predators, such as larvae-eating fish and adult mosquito-eating bats. In urban areas, environmental modifications (for example, culverts and drainage ditches), if properly maintained, can be important in the control of transmission.

Using new knowledge about the interactions between climate and disease, 14 southern African countries, including Mozambique, have established the Southern African Regional Climate Outlook Forum (SARCOF), to make use of seasonal forecasts to develop Health Early Warning Systems, plan public health interventions and allocate resources. Regional efforts like SARCOF have the potential to greatly reduce the intensity of malaria outbreaks, and such cooperative programs should be encouraged and supported.

Global initiatives have been developed to reduce the morbidity and mortality from malaria. The World Health Organization's "Roll-Back-Malaria" program and the Global Fund to Fight AIDS, Tuberculosis and Malaria have generated many programs to control malaria. The campaigns include community use of pesticide-impregnated bed nets (sometimes sold through "social marketing" schemes, elsewhere distributed free), pesticide (DDT or pyrethrins) spraying of houses, and mass treatment programs to interrupt transmission. The combination of approaches can be effective — if the programs are sustained. The long-term health, ecological, resistance-generating impacts and economic costs of pesticides used for control are always of concern.

Figure 2.7 Floodplains Provide Breeding Sites for Mosquitoes



Image: Creatas



## WEST NILE VIRUS

### A DISEASE OF WILDLIFE AND A FORCE OF GLOBAL CHANGE

Paul Epstein  
Douglas Causey

## BACKGROUND

West Nile virus (WNV), first identified in Uganda in 1937, is a zoonosis (a disease involving animals), with "spill-over" to humans. WNV poses significant risks to humans and wildlife as well as to zoo and domestic animals. The disease was unknown in the Americas until the summer of 1999, when it appeared suddenly in Queens, NY, and led to numerous cases with nervous system involvement and seven deaths in humans.

Since 1990, outbreaks of WNV encephalitis have occurred in humans in Algeria, Romania, the Czech Republic, the Democratic Republic of the Congo, Russia, Israel, the US, and Canada plus epizootics affecting horses in Morocco, Italy, El Salvador, Mexico, the US and France, and in birds in Israel and in the US. Since 1999 in the US, WNV activity in mosquitoes, humans or animals has been reported in all states except Hawaii, Alaska and Oregon (CDC 2005).

A new flavivirus, Usutu, akin to WNV, has recently emerged in Europe (Weissenböck et al. 2002). Many members of this Japanese B encephalitis family of viruses are capable of infecting humans, horses and wildlife.

## THE ROLE OF CLIMATE

While it is not known how WNV entered the US, anomalous weather conditions can amplify flaviviruses that circulate among urban mosquitoes, birds and mammals. Large European outbreaks of WNV in the past decade reveal that drought was a common feature (Epstein and DeFilippo 2001). An analysis of weather patterns coinciding with urban outbreaks of St. Louis encephalitis (SLE) in US cities reveals a similar association (Monath and Tsai 1987). SLE is referred to in this case study to analyze the meteorological determinants of WNV because of their similar life cycles, involving the same mosquitoes plus birds and animals. SLE first occurred in the US in 1933, during the 'Dust Bowl,' and low water tables are associated with SLE outbreaks in Florida (Shaman et al. 2002).

WNV is an urban-based mosquito-borne disease. *Culex pipiens*, the primary mosquito vector (carrier) for WNV, thrives in city storm-catch basins, where small pools of nutrient-rich water remain in the drains during droughts (Spielman 1967). Warm temperatures accompanying droughts also accelerate the maturation of viruses within the mosquitoes, enhancing the potential for transmission. Shrinking water sites can concentrate infected birds and the mosquitoes biting them, and drought may reduce the predators of mosquitoes, such as dragonflies and damselflies.

The first part of the life cycle of WNV and SLE is the "maintenance cycle." This involves the culex mosquitoes (that preferentially bite birds) and the birds. Drought and warmth appear to amplify this cycle, increasing the "viral load" in birds and mosquitoes. When droughts yield to late summer rains, other types of mosquitoes breed in the open, standing water. These mosquitoes bite birds, humans and other animals, acting as "bridge vectors" to transfer the infection.

Factors other than weather and climate contribute to outbreaks of WNV and SLE. Antiquated urban drainage systems leave more fetid pools in which mosquitoes can breed, and stagnant rivers and streams do

not adequately support healthy fish populations that consume mosquito larvae.

## SIGNIFICANT OUTBREAKS OF WNV IN THE PAST DECADE

**Romania 1996:** A significant outbreak of WNV occurred in 1996 in Romania in the Danube Valley and in Bucharest. This episode, with hundreds experiencing neurological disease and 17 fatalities, coincided with a prolonged drought and a heat wave (Savage et al. 1999).

**Russia 1999:** A large outbreak of WNV occurred in Russia in the summer of 1999, following a warm winter, spring drought and summer heat wave (Platanov et al. 1999).

**US 1999:** In the spring and summer of 1999, a severe drought (following a mild winter), affected Northeast and Mid-Atlantic states, and a three-week July heat wave enveloped the Northeast.

**Israel 2000:** WNV was first reported in Israel in 1951 (Marberg et al. 1956), a major stopover for migrating birds. In 2000 the region was especially dry, as drought conditions prevailed across southern Europe and the Middle East, from Spain to Afghanistan.

**US 2002-2005:** In the summer of 2002 much of the West and Midwest experienced severe spring and summer drought, compounded by a warm winter leaving little snowpack in the Rockies. An explosion of WNV cases occurred, across 44 states, the District of Columbia and five Canadian provinces. The summers of 2003 and 2004 saw persistent transmission in areas with drought, while spring rains and the summer drought in 2005 were associated with lower levels of transmission.

## HEALTH AND ECOLOGICAL IMPACTS

In the 1999 New York City outbreak, 62 people developed nervous system disease: encephalitis (brain inflammation) and meningoencephalitis (inflammation of the brain and surrounding membrane). Seven died and many of the 55 survivors suffered from prolonged or persistent neurological impairment (Nash et al. 2001). Subsequent outbreaks in the US include 4,161 cases and 284 deaths in 2002; 9,856 cases and

262 deaths in 2003; 7,470 cases and 88 deaths in 2004. The falling death rate suggests that the virulence of this emerging disease in North America is diminishing over time.

In the summers of 2003 and 2004, cases of WNV in the US were concentrated in Colorado and then California, Texas and Arizona — areas that experienced prolonged spring drought. The eastern US, with wet springs, had relatively calm seasons. In 2005, very variable conditions in the US were associated with an August surge of cases scattered across the nation, predominantly in the Southwest and California.

Most WNV infections are without symptoms. Approximately 20% of those infected develop a mild illness (West Nile fever), with symptoms including fatigue, appetite loss, nausea and vomiting, eye, head and muscle aches. Of those with severe disease, about two out of three can suffer from persistent fatigue and other neurological symptoms. The most severe type of disease affects the nervous system.

WNV has also spread to 230 species of animals, including 138 species of birds and is carried by 37 species of mosquitoes. Not all animals fall ill from WNV, but the list of hosts and reservoirs includes dogs, cats, squirrels, bats, chipmunks, skunks, rabbits and reptiles. Spread of WNV in North America follows the flyways of migratory birds (Rappole et al. 2000). In 2002, several zoo animals died and over 15,000 horses became ill; one in three died or had to be euthanized due to neurological illness.

The increasing domination of urban landscapes by “generalist” birds, like crows, starlings and Canada Geese, may have contributed to the spread of West Nile, along with the numerous mosquito breeding sites, like old tires and stagnant waterways. Fortunately, vaccines for horses and some birds are available, and newly released condors are being inoculated to stave off their “second” extinction in the wild.

WNV has spread to the Caribbean, it is a suspect in the decline in several bird species in Central America, and WNV killed horses in El Salvador in 2002 and in Mexico in 2003, the latter in clear association with drought. Monitoring birds in northern Brazil (along songbird flyways) and elsewhere would be warranted in Latin America.

Figure 2.8 Red-Tailed Hawk



*Some birds of prey have died from West Nile virus.  
Image: Matt Antonio/Dreamstime*

The population impacts on wildlife and biodiversity have not been adequately evaluated. The impacts of declines in birds of prey could ripple through ecological systems and food chains and could, in itself, contribute to the emergence of disease. Declines in raptors, such as owls, hawks, eagles, kestrels and marlins could have dramatic consequences for human health. (Some raptors have died from WNV, but the population-level impacts are as yet unknown.) These birds prey upon rodents and keep their numbers in check. When rodent populations “explode” — as when floods follow droughts, forests are clear-cut, or diseases attack predators — their legions can become prolific transporters of pests and pathogens. The list of rodent-borne ills includes Lyme disease, leptospirosis and plague, and hantaviruses and arenaviruses (Lassa fever, Guanarito, Junin, Machupo and Sabiá), which cause hemorrhagic fevers.

## ECONOMIC DIMENSIONS

The costs for treatment and containment of WNV disease in 1999 were estimated to be US \$500 million (Newcomb 2003). Subsequent health costs, screening of blood, community surveillance, monitoring and interventions have continued to affect life and health insurance figures, and the costs for cities and states to maintain surveillance and mosquito control for this urban-based mosquito-borne disease have been substantial.

The economic consequences of large epizootics (epidemics in animals) involving horses, birds and 300 other animals could involve direct losses in terms of tourism and indirect losses via changes in the balances of functional groups that help to keep pests and pathogens in check.

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Warming and the intensification of the hydrologic cycle may expose new areas and new populations to WNV. More frequent drought and higher temperatures might elevate baseline WNV infection rates in avian and mammal hosts and lead to even higher levels of viral amplification and larger epidemics. Increased flooding might lead to wider dispersal of infected vectors and avian hosts, putting more humans at risk. The human health risk will also depend on the interventions, as well as the population impacts and immunity built up among mammalian and avian hosts. Beyond the immediate morbidity and mortality of WNV, this disease can lead to long-term neurological disability, increasing the per capita loss in DALYs.

### CCF-II: SURPRISE IMPACTS

The most significant non-linear threat posed by WNV is the potential impact on wildlife, especially bird populations. Introduction of WNV into naïve populations in new areas, plus possible mutations to greater virulence, could lead to the extinction of vulnerable species. The impacts of extinction of keystone species (that provide essential functions, such as predation and scavenging) could ripple through ecological systems, releasing rodents from checks on their populations. For example, the rapid decline in vultures in India from poisoning with toxic medications picked up from garbage dumps (Kretsch 2003; Oaks 2003) has left “un-recycled” carcasses along roadsides. The dog populations filling in the niche are spreading rabies.

More flaviviruses, like Usutu, which recently appeared in Europe, could emerge in the coming years. A rash of illnesses of wildlife, especially mammals and birds, could have devastating impacts on predator/prey relationships and natural food webs.

The impact measured in DALYs would be quite substantial if West Nile virus spreads. Naïve populations of humans and wildlife in Latin America are particularly vulnerable. While the resources to control this disease exist in developed nations, large-scale outbreaks would tax public health infrastructures in developed and developing nations.

## SPECIFIC RECOMMENDATIONS

Surveillance and response plans are the first steps in the control of infectious diseases. Early warning systems, with climate forecasting and detection of virus in birds and mosquitoes, can help municipalities develop timely, environmentally friendly interventions.

Such measures include larvaciding of urban drains, particularly with the bacterial agent *Bacillus sphaericus* that is toxic for the culex larvae but innocuous for large animals and humans. The alternative is methoprene, a hormone-mimicking chemical that can enter water supplies and possibly cause harm to marine organisms.

“Source reduction” of breeding sites is key, including turning over discarded tires and cleaning drains, vases and backyard swimming pools. There are numerous means of individual protection against mosquito bites and vaccination can be protective for horses and perhaps some zoo animals.

Early interventions can limit the measures of last resort: the spraying of pesticides that may harm humans and wildlife. Street-by-street spraying is not very effective and aerial spraying is not innocuous, although pyrethrin agents (derivatives of chrysanthemum extracts) are much less toxic to humans than is malathion (which was previously used and is known to be harmful to birds and pollinating bees).

Above all, cities need plans, monitoring systems and communication methods to collect and disseminate information in a timely, well-organized fashion.



## LYME DISEASE

### IMPLICATIONS OF CLIMATE CHANGE

John Brownstein

#### BACKGROUND

Lyme disease is the most prevalent vector-borne disease in the continental United States. Lyme was discovered in 1977 when arthritis occurred in a cluster of children in and around Lyme, CT. Since that emergence, Lyme disease has spread throughout the Northeast of the US, two north-central states (Minnesota and Wisconsin) and the Northwest (California and Oregon). In these areas, between 1% and 3% of people who live there become infected at some time.

Lyme disease is also common in Europe, especially in forested areas of middle Europe and Scandinavia, and has been reported in Russia, China, and Japan. The deer tick, *Ixodes scapularis*, is the primary vector of *Borrelia burgdorferi*, the spirochete bacteria that is the agent of Lyme disease in North America (Keirans et al. 1996; Dennis et al. 1998). *I. scapularis* is also a known vector of human babesiosis, and human granulocytic ehrlichiosis (Des Vignes and Fish 1997; Schwartz et al. 1997).

Although the local abundance of vectors may be guided by "density-dependent" factors such as competition, predation, and parasitism, the geographic range of arthropod (tick) habitat suitability is controlled by other factors, such as climate.

#### ROLE OF CLIMATE

Climatic variation largely determines the maintenance and distribution of deer tick populations by regulating off-host survival (Needham and Teel 1991; Bertrand and Wilson 1996). The abiotic environment (that includes soils, minerals and water availability) plays a vital role in the survival of *I. scapularis* with both water stress and temperature regulating off-host mortality. As

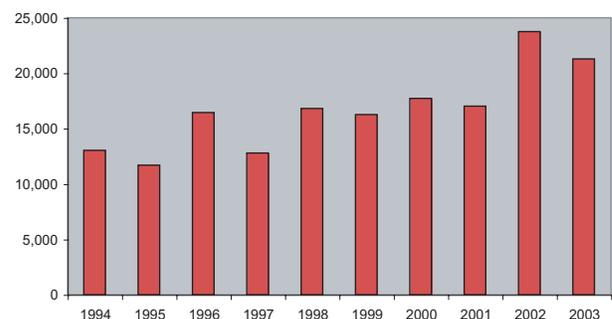
98% of the two-year life cycle takes place off the host, climate acts as an essential determinant of distribution of established tick populations across North America (Fish 1993).

Although recent emergence of Lyme disease throughout the northeastern and mid-Atlantic states has been linked to reforestation (Barbour and Fish 1993), additional influence of environmental change can be expected considering the anticipated shifts in climate.

#### HEALTH AND ECOLOGICAL IMPACTS

Lyme disease most often presents with a characteristic "bull's-eye" rash, called erythema migrans, surrounding the attached tick. The initial infection can be asymptomatic, but is often accompanied by fever, weakness, and head, muscle and joint aches. At this stage, treatment with antibiotics clears the infection and cures the disease. Untreated Lyme disease can affect the nervous system, the musculoskeletal system or the heart. The most common late manifestation is intermittent swelling and pain of one or several joints, usually large, weight-bearing joints such as the knee. Some infected persons develop chronic neuropathies, with cognitive disorders, sleep disturbance, fatigue and personality changes.

Figure 2.9 New Cases of Lyme Disease in the US: 1992-2003



Source: Centers for Disease Control and Prevention

#### ECONOMIC DIMENSIONS

Chronic disability is the primary concern with Lyme disease and as new populations are exposed in areas where the medical profession has little experience with this disease, such cases are projected to rise in the near-term. The productivity losses associated with chronic disabilities affect individuals, communities, work places and health insurance companies.

One analysis (Vanderhoof and Vanderhoof-Forschner 1993) conservatively estimated costs per case at about US \$60,000. Based on an annual mean incidence of 4.73 cases of Lyme disease per 100,000 population, a later decision analysis model (Maes et al. 1998) yielded an expected national expenditure of US \$2.5 billion (1996 dollars) over five years for therapeutic interventions to prevent 55,626 cases of advanced arthritis, neurological and cardiac disease. These figures may underestimate the true costs of the long-term disabilities incurred.

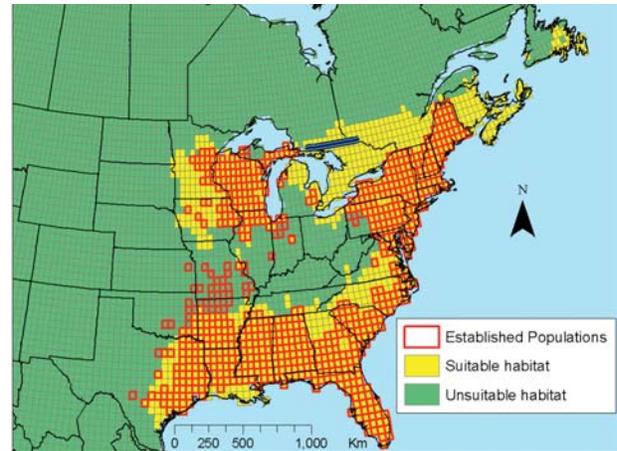
## THE FUTURE

### CCF-I: ESCALATING IMPACTS

The northward spread of warming conditions and warmer winters creates ideal conditions for the northward spread of Lyme disease into Canada, with continuing transmission in most of the regions with transmission currently. In some areas the abundance of ticks may increase as well, intensifying transmission. Expansion of the range of *Ixodes ricinus* in Sweden has already been documented and the northern migration is correlated with milder winters and higher daily temperatures (Lindgren and Gustafson 2001).

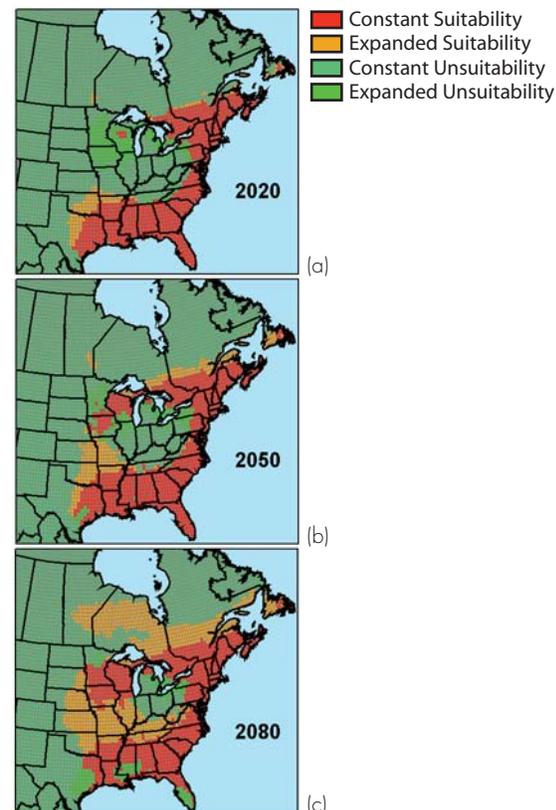
Model projections of the areas suitable for Lyme disease transmission show that maximum, minimum and mean temperatures, as well as vapor pressure, significantly contribute to the maintenance of populations in particular geographic areas.

Figure 2.10 Current Lyme Disease Habitat



Distribution of southern climate-based habitat suitability for *Ixodes scapularis* as predicted by the climate-based statistical model. Non-overlapped yellow pixels represent suitable areas that have yet to be colonized. The blue line across present-day Ontario represents the northern limit of habitat suitability predicted by Lindsay et al. (1995). Source: Brownstein et al. 2005

Figures 2.11 Lyme Model Projections



Projected distribution of climate-based habitat suitability for *Ixodes scapularis* during three future time periods: the 2020s (a), the 2050s (b), and the 2080s (c). The models project an increase in suitable habitat of 213% by the 2080s. Source: Brownstein et al. 2005

The rise in minimum temperature results in the expansion into higher latitudes, which is explained by the inverse relationship between tick survival and the degree of subfreezing temperature exposure (Vandyk et al. 1996). This trend is clearly shown by the spreading of suitable area north into Canada. Though *I. scapularis* has been collected from a variety of locations in Canada (Keirans et al. 1996, Scotter 2001), establishment has only been shown for a limited number of locations in southern Ontario (Schwartz et al. 1997). Climate change may provide the conditions necessary to yield reproducing populations of *I. scapularis* either by the systematic advancement from south of the border by movement on mammal hosts or by introductions via attachment to bird hosts (Klich et al. 1996).

Minimum temperature increase also results in the extension of suitability into higher altitudes. Elevation is an important limiting factor for *I. scapularis* populations as it indirectly affects population establishment through its influence on the complex interaction between climate, physical factors and biota (Schulze et al. 1994). As a result of increasing temperatures, the model predicts advancement of suitability into the southern Appalachian Mountains.

#### CCF-II: SURPRISE IMPACTS

Lyme disease is a slowly advancing disease, given its complex life cycle involving ticks, deer, white-footed mice and the supporting habitat and food sources for all these elements. Very warm winters may change the suitable habitat more rapidly than expectations based on changes in average temperatures alone. But, due to the many components of the life cycle, and the two-year cycle of the ticks themselves, it is unlikely that this disease will change its distribution and incidence abruptly and explosively.

## SPECIFIC RECOMMENDATIONS

Further study of Lyme disease and other tick-borne diseases is warranted. Tick-borne diseases include babesiosis (an animal, malaria-like illness), ehrlichiosis (bacterial), Rocky Mountain spotted fever and Q fever (rickettsial diseases), and especially in Europe, tick-borne encephalitis (a viral disease). The possible role of ticks is being studied in the investigation of an outbreak of tularemia ("rabbit fever") that has persisted on Martha's Vineyard, MA (USA) since 2000. A Lyme-like disease has been reported in the southern US (Mississippi, South Carolina, Georgia, Florida, and Texas) that also responds to antibiotics, and the possible role of other ticks in transmitting Lyme is under study.

Models that predict disease emergence can be valuable tools for preparing health professionals and strengthening public health interventions. Personal protective measures for high-risk populations can reduce infection rates. Environmental methods, including host-targeted vaccination and larvacides, have shown promise and have the potential to limit the spread of Lyme disease.

## BIODIVERSITY BUFFERS AGAINST THE SPREAD OF INFECTIOUS DISEASE

Figure 2.12



White tailed mouse that can transport Lyme-infected ticks, bacteria and viruses.

Image: John Good

Diversity of species and mosaics of habitat can help dampen the impacts of climate change that influence the colonization and spread of pests and infectious agents (Chivian 2001; Chivian 2002). Work at the Institute of Ecosystem Studies in New York State (LoGiudice et al. 2003) found that voles, squirrels and chipmunks — competitors of mice — are less susceptible to carrying the bacteria. Thus, greater biological diversity among rodent populations appears to “dilute” rates of infection and thereby reduce transmission.

Quantity of habitat matters. Maintaining extensive habitat that supports breeding populations of predators of rodents — for example, raptors, snakes and coyotes — is essential to keep in check populations of opportunists and “generalists” (those with wide-ranging diets, like most rodents), thereby controlling the prevalence of Lyme and other rodent-related diseases.

Preserving an abundance of animals and multiple groups performing similar functions, such as predation, is important for maintaining resilience (Lovejoy and Hannah 2005). A diversified portfolio of “insurance” species provides backup if some groups decline due to habitat change, greater climate variability or disease.

Another dimension of the protective role of biodiversity is found in the western US, where the blood of the Western fence lizard contains a chemical that destroys the causative bacteria, *B. burgdorferi*, for Lyme. This may help explain the low incidence of Lyme disease in the western US.

– P.E.



## CARBON DIOXIDE AND AEROALLERGENS

Christine A. Rogers

### BACKGROUND

Allergic diseases are the sixth leading cause of chronic illness in the US, affecting roughly 17% of the population. Approximately 40 million Americans suffer from allergic rhinitis (hay fever), largely in response to common aeroallergens. In addition, the Centers for Disease Control and Prevention (CDC) estimate asthma prevalence in the US at about 9 million children and 16 million adults (or 7.5% of the US population; CDC 2004). Both conditions taken together represent a significant population of adults and children suffering from chronic pulmonary symptoms. The self-reported prevalence of asthma increased 75% from 1980-1994 in both adults and children. However, the largest increase — 160% — occurred in preschool-aged children (Mannino et al. 1998). Low-income families and African Americans are disproportionately affected by increases in prevalence, morbidity and mortality (CDC 2004). While some recent reports suggest that these increases may be leveling off (or decreasing) (Hertzen and Haahtela 2005; Lawson and Senthilselvan 2005; Zollner et al. 2005), currently there is a much greater proportion of the population that is vulnerable to allergen exposure than ever before.

Although allergic diseases have a strong genetic component, the rapid rise in disease occurrence is likely the result of changing environmental exposures. There are many factors affecting the development of allergic diseases, and considerable attention has focused on the indoor environment (IOM 2000), lifestyle factors (Platts-Mills 2005), as well as outdoor particle exposures (Peden 2003). Diesel exhaust particles have been shown to act synergistically with allergen exposure to enhance the allergic response (Diaz-Sanchez et al. 2000; D'Amato et al. 2002). Thus, the combination of air pollution and allergen exposure may be one factor behind the epidemic of asthma being observed in developing and developed nations (Diaz-Sanchez et al. 2003).

While the role of allergen exposure alone in causing allergic diseases is unknown, allergens from pollen grains and fungal spores are unequivocally associated with exacerbation of existing disease. Changes in atmospheric chemistry and climate that tend to increase the presence of pollen and fungi in the air therefore contribute to a heightened risk of allergic symptoms and asthma.

## THE ROLE OF CLIMATE

### POLLEN

Several studies have explored the potential impacts of CO<sub>2</sub> and global warming on plants. In general, increasing CO<sub>2</sub> and temperatures stimulate plants to increase photosynthesis, biomass, water-use efficiency and reproductive effort (Bazzaz 1990; LaDeau and Clark 2001). These are considered positive responses for agriculture, but for allergic individuals, they could mean increased exposure to pollen allergens.

Figure 2.13 Pollen Grains



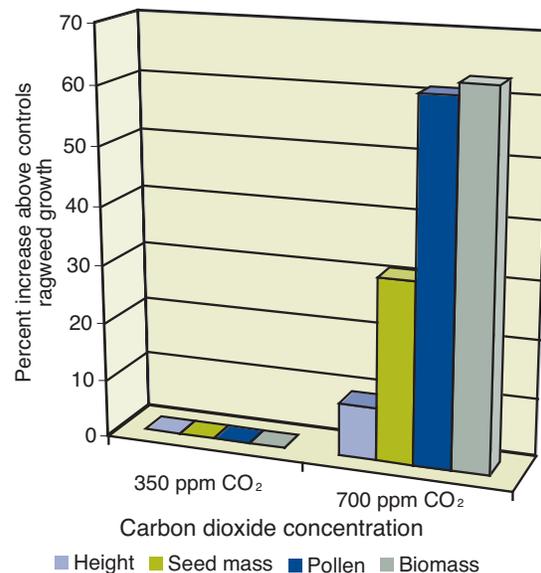
Electron microscope image of ragweed pollen grains.  
Image: Johns Hopkins University

Beyond these broad changes, climate warming has resulted in specific phenological changes in plants. First, the timing of spring budding has advanced in recent decades (Fitter and Fitter 2002; van Vliet et al. 2003). Hence the allergenic pollen season for many spring flowering plants also begins earlier (Jäger et al. 1996; Frei 1998; van Vliet et al. 2002). The rate of these advances is 0.84–0.9 days/year (Frenguelli et al. 2002; Clot 2003). While this is generally considered to be solely the effect of temperature, some studies suggest that CO<sub>2</sub> can independently affect the timing of phenological events as well (Murray and Ceulemans 1998).

Second, recent studies have shown increased plant reproductive effort and pollen production under conditions of elevated CO<sub>2</sub>. For example, loblolly pines respond to experimentally elevated CO<sub>2</sub> (200 ppm above ambient levels) by tripling their production of seeds and cones (LaDeau and Clark 2001). Long-term records at pollen monitoring stations in Europe show increasing annual pollen totals for several types of trees including hazel, birch and grasses (Spieksma et al. 1995; Frei 1998).

For ragweed (*Ambrosia artemisiifolia*), a weed of open disturbed ground that produces potent pollen allergens, controlled-environment experiments show that plants grown at two times ambient CO<sub>2</sub> have greater biomass, and produce 40% to 61% more pollen than do controls (Ziska and Caulfield 2000; Wayne et al. 2002) (see figure 2.13). This finding was corroborated in field experiments using a natural urban-rural CO<sub>2</sub> gradient (Ziska et al. 2003).

Figure 2.14 Ragweed Pollen Production Under Elevated CO<sub>2</sub>



Plants grown at high CO<sub>2</sub> levels grow moderately more (9%) but produce significantly more (61%) pollen than those grown at lower levels. Source: Wayne et al. 2002

Increased temperature and CO<sub>2</sub> can also have interactive effects on pollen production due to longer growing seasons. In experiments simulating early spring, ragweed plants grew larger, had more flowers and produced more pollen than did plants started later. Those started later with high CO<sub>2</sub> produced 55% more pollen than did those grown at ambient CO<sub>2</sub> (Rogers et al. *in review*).

Figure 2.15 Ragweed



Image: Dan Tenaglia/Missouriplants.com

There are many ways climate change will alter the timing, production and distribution of airborne pollen allergens. For example, climate variability may alter the frequency of masting (periodic bursts of simultaneous reproduction of trees), which results in huge fluxes of airborne pollen from year to year. In addition, shifts in the distributions of species due to shifts in temperature regimes are also likely, as some species will be able to take advantage of new conditions while others will not (Ziska 2003). In some instances new habitats will be created for weeds after drought and fire. Lastly, although increased spring rainfall in some years and in some regions could decrease overall airborne concentrations (through washout) even if more pollen is produced, most changes in environmental factors act to increase the availability of pollen allergens.

Figure 2.16 Soil Fungi



Many soil fungi are arbuscular mycorrhizal fungi, living symbiotically with trees supplying nutrients and recycling decayed matter. Mushrooms are their flowering bodies.

Image: Sara Wright/USDA Agricultural Research Service

## MOLDS

Long-term field experiments show that elevated  $\text{CO}_2$  stimulates some symbiotic fungi (in mycorrhizal associations with tree roots) to grow faster and produce more spores (Klironomos et al. 1997; Treseder et al. 2003; Wolf et al. 2003). While further study is needed to examine this effect for a wide range of fungi and their complex associations in the ecosystem (Klironomos 2005), it is likely that higher  $\text{CO}_2$  will enhance fungal growth directly created by  $\text{CO}_2$ , and indirectly as fungi respond to the presence of increased plant biomass.

Figure 2.17 Household Mold



Household mold often follows flooding.

Image: Chris Rogers

## HEALTH AND ECOLOGICAL IMPACTS

Air quality directly affects the presence of asthma symptoms. A complex, serious condition characterized by shortness of breath, wheezing, airway obstruction, and inflammation of the lung passages, asthma commonly begins in childhood and requires frequent doctor visits, medications, emergency visits or hospitalizations.

For developing nations and for those in poor communities, the health impacts of asthma can be significant. As developing countries incorporate modern technologies to cope with climate change (for example, air conditioning) on a wider scale, the resulting mold problems associated with poor building construction and maintenance will also increase without an influx of financial and technical resources.

# AIR QUALITY AND CLIMATE CHANGE ISSUES

- **Forest fires** in Southeast Asia and in the Amazon are generating significant quantities of respiratory irritants, while harming wildlife and releasing large pulses of carbon into the atmosphere.
- **Dust**, containing particles and microbes, from regions plagued by persistent drought, is being carried in large clouds over long distances. Dust clouds from African deserts, following the same trade winds that drove the “triangular trade,” are now exacerbating asthma in Caribbean islands, with implications for health of islanders and for tourism.
  - In 2005, the extent of the dust cloud crossing the Atlantic reached the size of the continental US. Desertification of Africa’s Sahel region bordering the Sahara (from overgrazing and climate changes) generates the enormous clouds of dust and soil microorganisms. Meanwhile, temperature gradients in the Atlantic Ocean created by North Atlantic freshening and tropical ocean warming are propelling the vast dust clouds rapidly across the Atlantic (Hurrell et al. 2001).
  - In recent years asthma has skyrocketed in several Caribbean Islands. Once rare among the islands enjoying ocean breezes, today one in seven children suffer from asthma on Barbados and one in four in Trinidad. Asthma attacks peak when dust clouds descend (Gyan et al. 2005).
- Vast **hazes** of air pollutants from coal-fired plants and automotive emissions are accumulating over large parts of Asia, affecting respiratory health, visibility and the local climate (Ramanathan et al. 2001).
- **Increased carbon dioxide** has been shown to stimulate reproduction in trees (for example, pines and oaks) and pollen production in ragweed.
- **Photochemical smog** (ground-level ozone) results from the reactions among several tailpipe emissions: nitrogen oxides (NO<sub>x</sub>s) and volatile organic compounds (VOCs), which combine rapidly during heat waves.

- **Heat waves**, unhealthy air masses, high heat indices (a function of temperature and humidity), plus lack of nighttime relief all affect respiratory and cardiac conditions and mortality.
- **Particulates**, carbon monoxide, smog and carcinogenic polycyclic aromatic hydrocarbons from drought-driven wildfires can affect populations living at great distances from the fires.
- **Floods** foster fungal growth in houses.

– P.E.

## ECONOMIC DIMENSIONS

Asthma is therefore a significant expense for society and health care systems. The total costs of asthma in the US are estimated to have increased between the mid-1980s and the mid-1990s from approximately US \$4.5 billion to over US \$10 billion. Weiss and colleagues estimated the total asthma costs for Australia, the UK and the US (adjusted to 1991 US dollars for comparison purposes) at US \$457 million, US \$1.79 billion and US \$6.40 billion, respectively. Updating these figures to 2003 dollars using the Consumer Price Index (CPI) yields approximately US \$617 million, US \$2.42 billion and US \$8.64 billion, respectively. These data are probably underestimates, as the prevalence of asthma was rising steadily during this period.

Beyond immediate costs of health care — clinic visits, emergency room visits, hospitalizations, and medications — are the less tangible losses due to school absences and work absences. There are approximately 37 million lost days of work and school due to allergic diseases (AAAAI 2000).

While the total costs of asthma health care in the US in 1998 were estimated to be US \$12.67 billion (based on 1994 actual costs adjusted to 1998 dollars using the CPI), and the adjusted cost (using the CPI) projected to 2003 would be US \$13.34 billion, the annual direct and indirect costs for asthma rose from US \$6.2 billion in the 1990s (Weiss et al. 1992) to US \$14.5 billion in 2000 (AAAAI 2000).

For allergic rhinitis the total direct and indirect cost estimates rose from US \$2.7 billion in the 1990s (Dykewitz and Fineman 1998) to US \$4.5 billion this decade (AAAAI 2000).

## ASTHMA COSTS TODAY

- Direct health care costs for asthma in the US total more than US \$11.5 billion annually (2004 dollars).
- Asthma causes approximately 24.5 million missed work days for adults annually.
- Reduced productivity due to death from asthma represents the largest single indirect cost related to asthma, approaching US \$1.7 billion annually.
- Indirect costs from lost productivity add another US \$4.6 billion for a total of US \$16.1 billion annually.
- Prescription drugs represented the largest single direct medical expenditure, over US \$5 billion.
- Approximately 12.8 million school days are missed annually due to asthma.
- Overall allergies cost the health care system US \$18 billion annually.

Source: American Lung Association 2005

### THE FUTURE

#### CCF-I: ESCALATING IMPACTS

Some 300 million people worldwide are known to suffer from asthma, and that number is increasing. By 2025 there could be an additional 100 million diagnosed asthmatics due to the increase in urban populations alone.

Worldwide the number of DALYs lost due to asthma is estimated at 15 million per year. This number and the associated burdens and costs are likely to increase steadily under CCF-I. The costs associated with allergic disease will likely continue to rise along a similar trajectory, suggesting a figure well over US \$30-40 billion annually over the coming decade.

#### CCF-II: SURPRISE IMPACTS

With continued rise in CO<sub>2</sub>, early arrival of springs, and continued winter and summer warming, the growth of weeds may be stimulated to such an extent that the chemicals used for control could do more 'collateral damage' to friendly insects, pollinators and birds than they do to the pests and weeds they are designed to control. This pattern would, in short order, be unsustainable for agricultural systems. Repetitive wildfires would also alter air quality in more regions of the globe. Areas plagued by persistent drought (as

examples, the African Sahel and China's Gobi desert) now annually generating millions of tons of dust (containing particulates and microorganisms), will increase, further swelling the burden of respiratory disease.

Automobile congestion, coal-fired energy generation, and forest fires in Southeast Asia and Latin America add additional respiratory irritants, and large pulses of carbon. Forest pest infestations will add fuel for fires in tropical, temperate and northern regions.

The combination of more aeroallergens, more heat waves and photochemical smog, greater humidity, more wildfires, and more dust and particulates could considerably compromise respiratory and cardiovascular health in the near term. Widespread respiratory distress is a plausible projection for large parts of the world, bringing with it increasing disability, productivity losses, school absences, and rising costs for health care and medications.

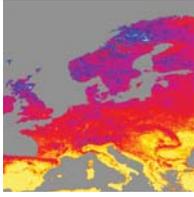
Under CCF-II, asthma management plans by individuals and health care services would be less effective, resulting in significant increases in morbidity and mortality.

### SPECIFIC RECOMMENDATIONS

Individual measures to reduce exposures to indoor and outdoor allergens can reduce the morbidity and mortality from asthma. Treatment options for allergies and asthma are changing rapidly and early interventions, support groups of patients and family members, and community education can help reduce illness, emergency room visits and hospitalizations.

Environmental measures that reduce ragweed growth will reduce pollen counts. Urban gardens, containing plants carefully chosen for lower allergenicity, can replace abandoned city lots where ragweed grows. The measures (addressed in the heat wave case study) to reduce the "heat island effect" in cities will reduce "the CO<sub>2</sub> dome" as well. Limiting truck and bus idling can reduce diesel particulates and emissions that combine to form smog. Improved public transport, expanded biking lanes and walking paths, and smart growth in cities and suburbs can limit automotive congestion. Replacement of coal-fired utility plants with those powered by natural gas and combined-cycle uses of energy generation in chemical and manufacturing plants (capturing escaping heat to heat water), energy conservation and greater efficiency, smart and hybrid technologies, and distributed generation of energy (discussed in Part III) are all important in improving air quality and reducing carbon dioxide emissions — locally and globally.

## EXTREME WEATHER EVENTS



### HEAT WAVES

#### CASE 1. THE 2003 EUROPEAN SUMMER HEAT WAVE AND ANALOG STUDIES FOR US CITIES

Laurence S. Kalkstein  
J. Scott Greene  
David M. Mills  
Alan D. Perrin

#### BACKGROUND

In the past two decades, severe heat events affecting thousands of people have occurred in London, Calcutta, Melbourne and Central Europe. In the US there is a well-documented pattern of increased urban mortality as a result of heat waves in the past several decades (for example, St. Louis, 1980; New York,

1984 and 1999; Philadelphia, 1991 and 1993; Chicago, 1995).

The summer of 2003 in Europe was most likely the hottest summer since at least AD 1500 (Stott et al. 2004) and the event had human and environmental impacts far beyond what linear models have projected to occur during this century. An event of similar magnitude in the United States could cause thousands of excess deaths in the inner cities and could precipitate extensive blackouts.

#### THE ROLE OF CLIMATE

Heat waves have become more intense and more prolonged with global warming (Houghton et al. 2001), and the impacts are exacerbated by the disproportionate warming at night that accompanies greenhouse gas-induced warming (Easterling et al. 1997). More hot summer days, higher maximum temperatures, higher minimum temperatures and an increase in heat indices (humidity and heat) have been observed in the 20th century, and models project that these elements are “very likely” to increase during the 21st century (Easterling et al. 2000).



Image: Photodisc

Stott et al. (2004) calculate that anthropogenic warming has increased the probability risk of such an extreme event two to four fold "... with the likelihood of such events projected to increase 100-fold over the next four decades, it is difficult to avoid the conclusion that potentially dangerous anthropogenic interference in the climate system is already underway ... by the end of this century 2003 would be classed as an unusually cold summer. ..."

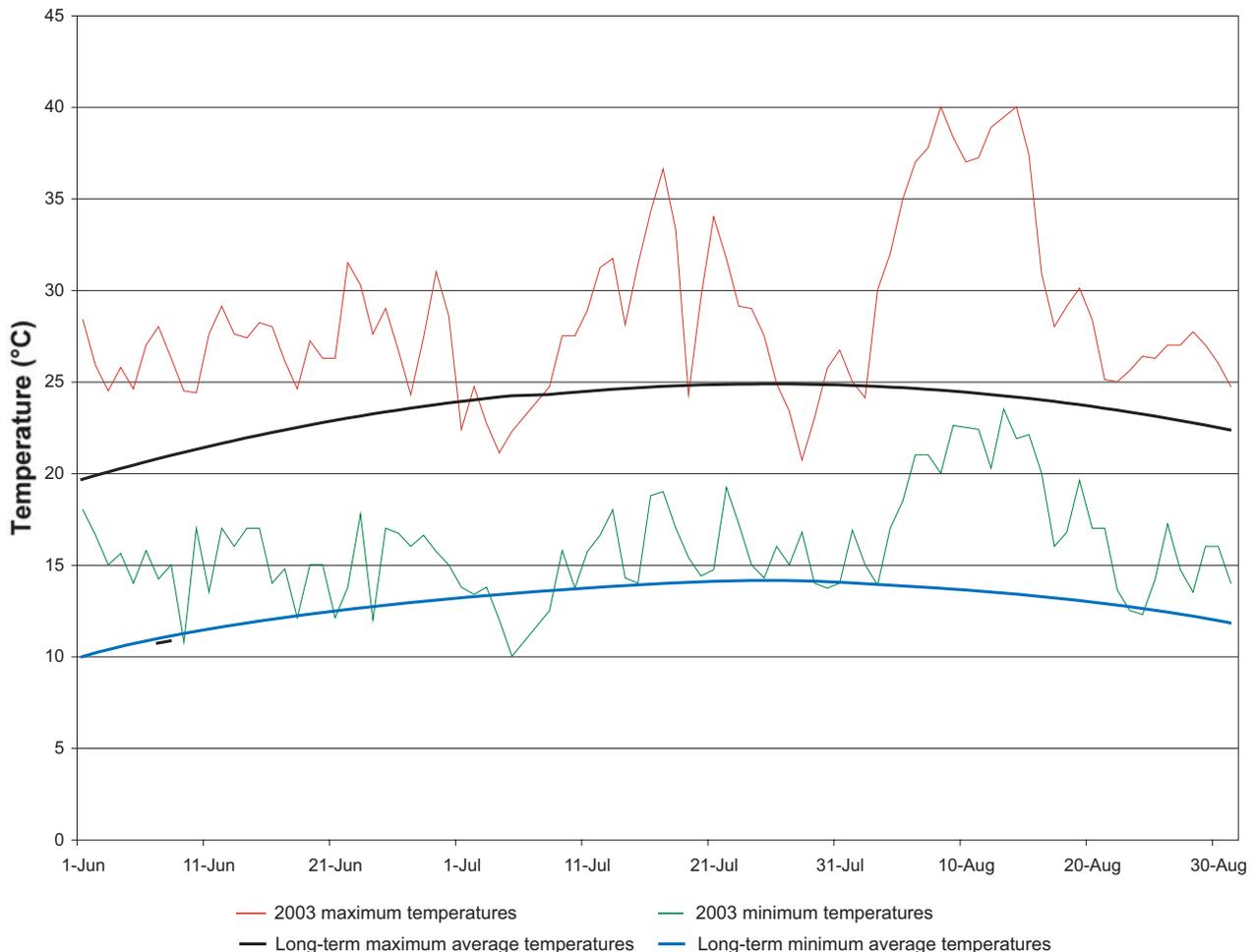
## EUROPEAN HEATWAVE 2003

The heat and the duration of the 2003 heatwave were unprecedented, with summer temperatures 20% to 30% higher than the seasonal average over a large part of Europe, from Spain to the Czech Republic (UNEP 2005). Temperatures were 6°C (11°F) over long-term averages since 1851 (Stott et al. 2004) and, by grape growing records, the event had no equal since 1370 (Chuine et al. 2004). For the

period 1 June through 31 August 2003, maximum temperatures in Paris were above average for all but eight days, and the average maximum temperatures were 10°C (18°F) greater than the 30-year average (see figure 2.17). Minimum temperatures were also abnormally above average. Temperatures were well above average for most of the 2003 summer in a broad region extending from the British Isles to the Iberian Peninsula and eastward to Germany and Italy, while the worst conditions were centered in France.

Schar et al. (2004) suggest that the return period of a heat wave of this magnitude is between 9,000 and 46,000 years. The intense and widespread heat anomalies in the summer of 2005 suggest that the return times for such very extreme events may already be shortening at a faster pace than models have projected.

Figure 2.18 Paris Temperatures in Summer 2003



Actual vs. average maximum and minimum temperatures for Paris, France, during summer of 2003.  
Source: Kalkstein et al. in review

## HEALTH AND ECOLOGICAL IMPACTS

Heat is associated with excessive mortality via several pathways: Dehydration and heat stroke are primary. Other conditions that can be precipitated include cardiovascular collapse and cerebrovascular and respiratory distress.

The number of lives lost in 2003 was estimated to be between 22,000 and 35,000 in five European countries. There was also an upsurge of respiratory illness from fires and release of particulates, plus high ozone levels (registered in Switzerland).

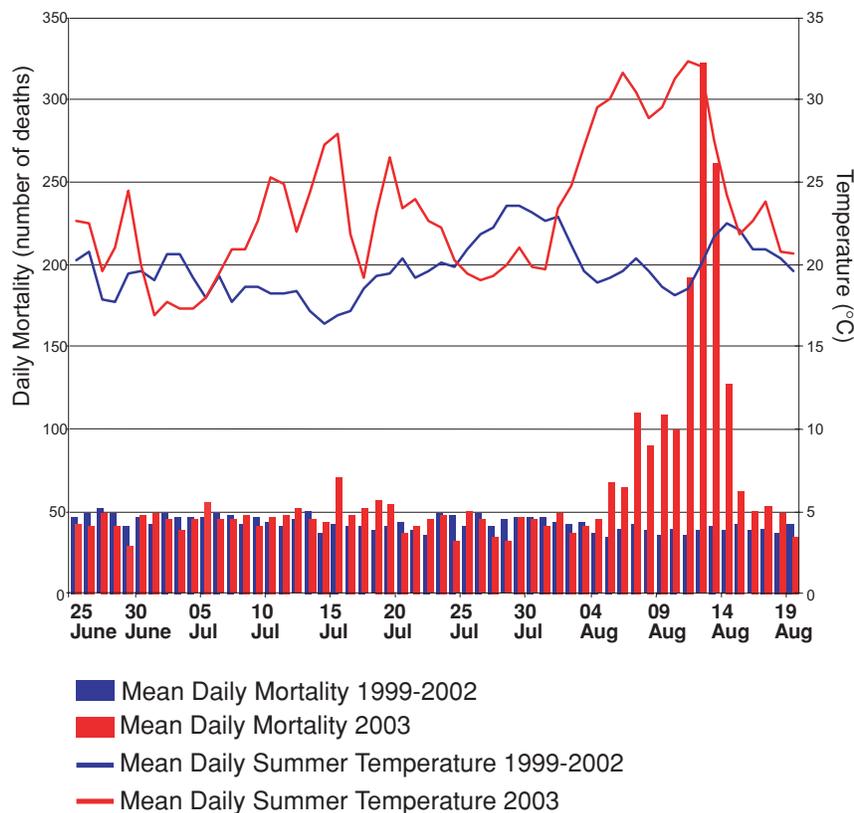
In Paris, aged populations were the most severely affected. Of the 2,814 deaths occurring in one health facility (with core temperatures equal to or above 40.6°C or 105°F) between 8-19 August, 81% were people over 75 years of age and 65% were females (Hémon and Jouglé 2003).

The environmental and ecological impacts of the prolonged heat spell included loss of livestock (for example, chickens), wilted crops (already stressed from the late spring frost), and loss of forest cover and wildlife. The soils of the region experienced a net loss of carbon (Ciasis et al. 2005; Baldocchi 2005). An estimat-

ed 10% of total mass of the ice cover of the Alps was lost in 2003; five times the average annual loss from 1980-2000 (UNEP 2004). Alpine glaciers had already lost more than 25% of their volume since 1850. At these rates, less than 50% of the glacier volume in 1970-80 will remain in 2025 and approximately 5% will be left in 2100 (UNEP 2004). Thawing permafrost also led to rockfalls and the accumulation of melt water in lakes precariously located near settlements, increasing the vulnerability to future avalanches and flash floods.

According to the UNEP brief (2004) on fires linked to the heat catastrophe of summer 2003, more than 25,000 fires were recorded in Portugal, Spain, Italy, France, Austria, Finland, Denmark and Ireland. The estimated forest area destroyed reached 647,069 hectares. Portugal was the worst hit with 390,146 hectares (ha) burned, destroying around 5.6% of its forest area. Spain came in second with 127,525ha burned. The agricultural area burned reached 44,123 ha plus 8,973 ha of unoccupied land, and 1,700 ha of inhabited areas. This was by far the worst forest fire season that Portugal had faced in the last 23 years. In October 2003, the financial impact estimated by Portugal exceeded 1 billion euros.

Figure 2.19 The Paris Heat Wave: Deaths and Temperatures



Mean temperature and associated mortality for Paris, France: summer 2003 and average summers.  
Source: Kalkstein et al. in review

In the summer of 2005, northern Spain and the north and midsections of Portugal experienced fires of a similar magnitude.

## ECONOMIC DIMENSIONS

The economic losses included life insurance payments for heat wave and wildfire deaths, property damage and direct health costs, including hospital stays, clinic treatments and ambulance rides. The livestock and crop losses (largely uninsured by private companies) were approximately US \$12.3 billion, including US \$230 million in Switzerland. Potato, wine, cereal and green fodder production were all seriously affected (UNEP 2004). Fire and timber losses included 400,000 acres in Portugal (approximately 14% of its forest cover), costing about US \$1.6 billion. And the cost of monitoring and preparations in subsequent years was estimated to be US \$500 million annually.

## ECONOMIC AND HEALTH PATHWAYS

- Lives lost
- Health care costs
- Life insurance policies
- Losses in productivity
- Agricultural and livestock losses
- Wildfires
- Hydroelectric power losses
- Business interruptions
- Travel restrictions
- Tourism losses

Airlines, hotels, restaurants, auto rental agencies and the skiing industry were also affected; there were business interruptions and conference cancellations (minimal, as it was summer) and interruptions of power due to overheating of cooling water for nuclear power plants. Over the summer of 2003 electricity spot prices rose beyond EU 100 (US \$130) per MWh (Allen and Lord 2004; Schar and Jendritzky 2004; Stott et al. 2004).

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Models of heatwave impacts for the next several decades project a doubling to tripling of mortality in many urban centers in the US. Absent from these models are projections of variability. Schar et al. (2004)

found that variability in weather over a seasonal scale helps account for the magnitudes of European summer heat waves.

Heat waves in developing nations present even greater threats, as resources are often inadequate and more people live under vulnerable conditions. In the summer of 2003, while Europe sweltered, Andhra Pradesh, India, experienced temperatures of 122°F with over 1,400 heat-related deaths, followed by heavy rains and an outbreak of the mosquito-borne Japanese B encephalitis.

Heat waves of the magnitudes projected by linear models over the next several decades could tax health facilities, public health officials, insurance companies, and energy grids. The potential for brown- and black-outs increases with the intensity, geographic extent and the duration of heat waves.

### CCF-II: SURPRISE IMPACTS

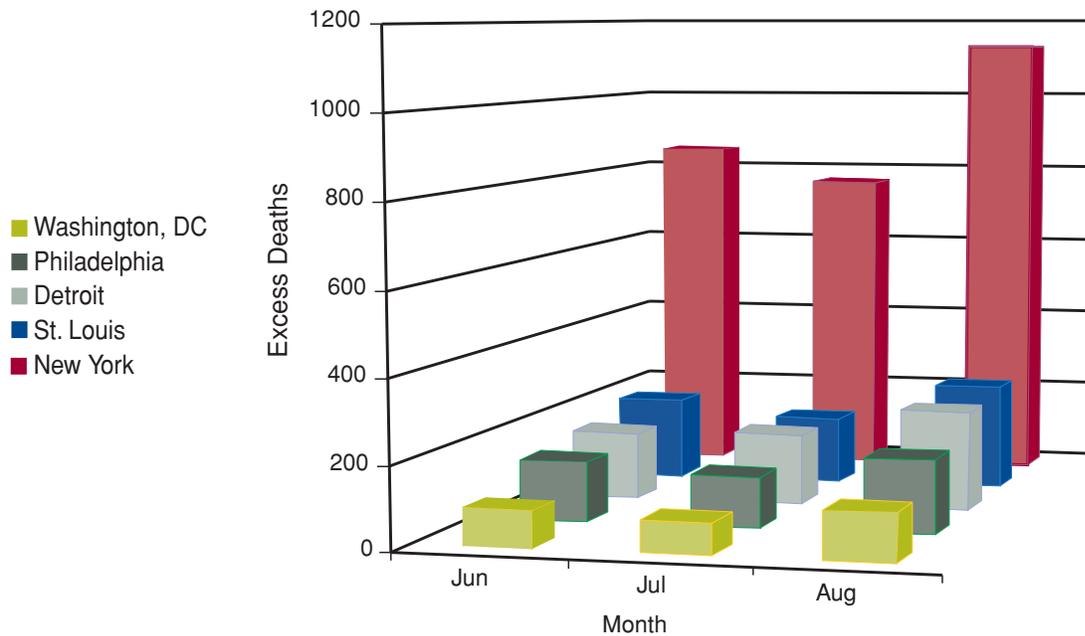
## What if Europe's extreme summer of 2003 came to the US?

Given the magnitude and duration of the event in Europe in summer 2003, it is clear that linear models do not accurately reflect the potential degree of extremes in the near future. A heat wave of similar magnitude in the US could have wide-ranging impacts, including overload of the power grid, increasing the potential for wide-scale blackouts and business interruptions.

Heat waves have the potential to cause significant mortality among the elderly and children over the coming century. In addition, electricity grids are inadequate to absorb the additional loads. Brownouts and blackouts would further exacerbate the health impacts of heat waves, affecting air conditioning and treatment facilities.

Here we analyze analogs of the 2003 heat wave for five US cities: Detroit, New York, Philadelphia, St. Louis and Washington, DC. As this unprecedented heat event in Europe is now part of the historical record, a realistic analog can be used to assess the risks of increasing heat on these cities that is independent of general circulation models (GCMs) and arbitrary scenarios. The analogs can be utilized for impact-related climate analysis in a variety of areas, including agriculture, forestry, infectious disease, water resources and the energy infrastructure.

Figure 2.20 Projected Excess Deaths in Five US Cities Under Europe-2003 Conditions



## EXCESS MORTALITY IN THE ANALOG EVENTS

Today, approximately 1,000 people die of heat-related causes in the 44 largest US cities and between 1,500 and 2,000 for the entire country (Kalkstein and Greene 1997). With this in mind, the number of excess deaths estimated for each of the five cities under analog heat wave conditions is staggering. For New York City alone, excess mortality during the analog summer is nearly 3,000.

- Excess deaths (which are assumed to be heat-attributed) were very high for the analog summer, with an estimated total across all locations that was more than five times the average. New York's total alone exceeded the national summer average for heat-related deaths.
- New York and St. Louis had the highest death rates for the analog summer due to the many high-rises and brick row-homes with black tar roofs that absorb a lot of heat.

## KEY PROJECTIONS FROM THE US ANALOG STUDIES

- Summer frequencies of the unhealthy, "offensive air masses" (see Appendix B for definitions) ranged from almost 200% to over 400 % above average during the analog summer in the five cities. Frequencies also exceeded the hottest summer over the past 59 years by a significant margin.
- Consecutive days of unprecedented length with unhealthy air masses were a hallmark of the analog heat wave, and the strings of days occurred on two different occasions during the summer.
- All-time records for maximum and high minimum temperature were broken in all cities, and, in some locales, there were consecutive days breaking all-time records.

## SPECIFIC RECOMMENDATIONS

### HEAT/HEALTH WATCH WARNING SYSTEMS

Early warning systems have been shown to effectively reduce mortality associated with heat waves (Kalkstein 2000; Ebi et al. 2004; Smith 2005). The principal components of early warning systems include meteorological forecasts, models to predict health outcomes, effective response plans, and monitoring and evaluation plans, set within disaster management strategies. The meteorological component should incorporate projected increases in climate variability by considering scenarios of weather anomalies outside the historic range. Models of adverse health outcomes need to project changes in incidence accurately, specifically and rapidly enough for effective responses to be implemented. Because early warnings alone are not sufficient to guarantee that necessary actions will be taken, prevention programs need to be designed with

a better understanding of subpopulations at risk and the information necessary for effective response to warnings. Monitoring and evaluation of both the response system and individual interventions need to be built into system design to ensure the efficient and effective use of resources.

#### RESPONSES INCLUDE:

- Improved social networks and neighborhood response plans to transport isolated persons to facilities with adequate air conditioning (malls, theaters)
- Transport vehicles
- Air-conditioned facilities in group-housing settings
- Prepared and well-distributed treatment facilities.

A number of structural changes can ameliorate the health impacts of heat waves by reducing the heat-island effect. (These same measures would stimulate production and open markets for alternative and energy-efficient energy technologies. They are examples of harmonizing adaptation and mitigation. See Part III for further discussion.)

#### STRUCTURAL MEASURES INCLUDE:

- “Green buildings,” with relevant building codes and insurance policies
- Roof gardens to absorb heat
- Treelined streets to absorb heat
- Adequate public transport systems to decrease traffic congestion
- Bicycle and walking paths
- “Smart growth” of urban and suburban areas to minimize commutes
- Hybrid and renewable energy-powered vehicles to reduce pollution.

#### OTHER MEASURES INCLUDE:

- Improved power grids
- “Smart” technologies that improve efficiency of utility grids by favoring high-use areas during specific hours of the day
- Distributed power generation to complement and supplement grids (discussed in Part III).

#### RESEARCH IMPLICATIONS

Questions remain regarding agricultural yields in response to such an extreme summer; how these conditions would impact water resources, livestock, wild

animal and freshwater fisheries management; and what effect such extremes would have on electricity generation and transmission. These analogs can be utilized much like modeled meteorological data sets and the methods can be expanded to include other midlatitude locations around the world.

Figure 2.21



Wildfires in New South Wales, Australia, summer 2003.  
Image: CSIRO Forestry and Forests Products Bushfire Behaviour and Management Group

## CASE 2. ANALOG FOR NEW SOUTH WALES, AUSTRALIA

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### BACKGROUND

Heat, drought, and bushfires are not new to Australia. Between 1967 and 1999, bushfires in Australia resulted in 223 deaths and 4,185 injuries with a cost of over US \$2.5 billion, not including timber losses. The drought in southeastern Australia in the austral summer of 2003 was particularly intense and sparked widespread fires. The January fires alone destroyed over 500 homes, claimed four lives in Canberra and caused over US \$300 million in damages (Australian Government 2004).

The heat wave that Europe experienced during August 2003 revealed the susceptibility of even the industrial affluent world, rich in infrastructure, when maximum temperatures soared to 10°C above the historical average, and minimum temperatures reached record high levels. In July 1995, the heat wave in Chicago (USA), where maximum temperatures ranged between 33.9°C and 40.0°C, resulted in an excess of 700 heat-attributable deaths, an 85% increase in mortality compared to the previous year (CDC 1995). What would be the impact on mortality if Australia were to experience a heat wave similar to that of the European summer of 2003?

## THE ROLE OF CLIMATE

Australia experiences a wide range of climatic conditions, varying from the tropical north to the temperate south, and is one of the continents most affected by the El Niño/Southern Oscillation (ENSO) phenomenon, which also influences the occurrence of heat waves (Bureau of Meteorology 2003). Heat waves have caused more fatalities during the 20th century in Australia than any other natural weather hazard (EMA 2003).

While heat waves are not infrequent in Australia, recent extreme climate occurrences suggest that, as global warming proceeds, we will face more frequent and extreme hot days. Globally, June 2003 saw the second highest land temperatures (0.96°C above the long term mean) being recorded (NCDC 2003). In 2002, South Australia recorded the highest ever maximum summer temperatures (Bureau of Meteorology 2002). Meanwhile, analysis of daily temperature records from the Commonwealth Bureau of Meteorology for Sydney airport for the period 1964–2002 indicates that there has been a modest upward trend in the number of days per year with maximum temperatures exceeding 35°C.

### What if Europe's extreme summer of 2003 came to New South Wales, Australia?

Based on the 2003 French heat wave, a hypothetical scenario was developed for urban New South Wales, which includes Sydney, Australia's largest city and the capital. In France, an approximate 10°C rise in temperature over a 14-day period resulted in a 55% increase in mortality compared to the preceding year (InVS 2003). If NSW were to experience a heat-wave with the variations from norm that France experienced, given an annual mortality rate for urban NSW of 591 deaths per 100,000, and a population of approximately 5,200,000, we estimate an overall excess of 647 deaths over and above the 1,176 deaths otherwise expected in urban NSW during a 14-day period.

The August 2003 mortality excess in France, especially in urban areas, was amplified by coexistent high levels of photochemical ozone (Fiala et al. 2003). Ozone, while shown to increase deaths from cardio-respiratory disease (Simpson et al. 1997; Morgan et al. 1998a,b), has also been shown to compound the

impacts of heat (Katsouyanni et al. 1993; Rainham et al. 2003; Sartor 1994). If (perhaps unusually) the hypothetical extreme heat wave in urban New South Wales were not accompanied by increased air pollution, the expected impact on mortality would be less and our figures accord with the incremental risks seen at the high temperature end of the temperature-mortality dose-response curves previously published for various temperate-zone cities (Hales et al. 2000; Huynen et al. 2001; Hajat et al. 20002; Pattenden et al. 2003).

An excess mortality within the range 25-55% would be much greater than that usually experienced in past heat waves in Australia. Historically, severe heat waves in other nearby or similar parts of the world have typically caused 10-20% excess deaths (Pattenden et al. 2003; Huynen et al. 2001). However, there are certain factors that are likely to contribute to increased impacts in the present and future. For example, Australia has an aging population (AIHW 1999). With increasing numbers of elderly, the occurrence of chronic disease and co-morbidities increase. Elderly with underlying disease, particularly cardiovascular disease, and people living alone, have been identified as being more susceptible to the effects of heat waves. Australia also has a high level of urbanization, with an estimated 84.7% of the population living in an urban location (UNCHS 2001). This means that a high proportion of the population is likely to be exposed to air pollutants and the urban heat-island effect. While the air quality in Australia is relatively good by international standards, it is important to note the conditions are changing. In Sydney, for example, the annual number of days on which the photochemical ozone standard (0.10 ppm for a one-hour average) was exceeded has risen from zero in 1995 to 19 in 2001 (NSWH 2003). This increases the susceptibility to the impacts of heat waves.

Australia is also experiencing more hot days, with predictions that the number of summer days over 35°C in Sydney will increase from current two days up to eleven days by 2070 (CSIRO 2001). Given all these factors, it is not unlikely that the adverse impact of heat waves in Australia will increase with time.



## FLOODS

### FOCUS ON THE 2002 FLOODS IN EUROPE

Kristie L. Ebi

#### BACKGROUND

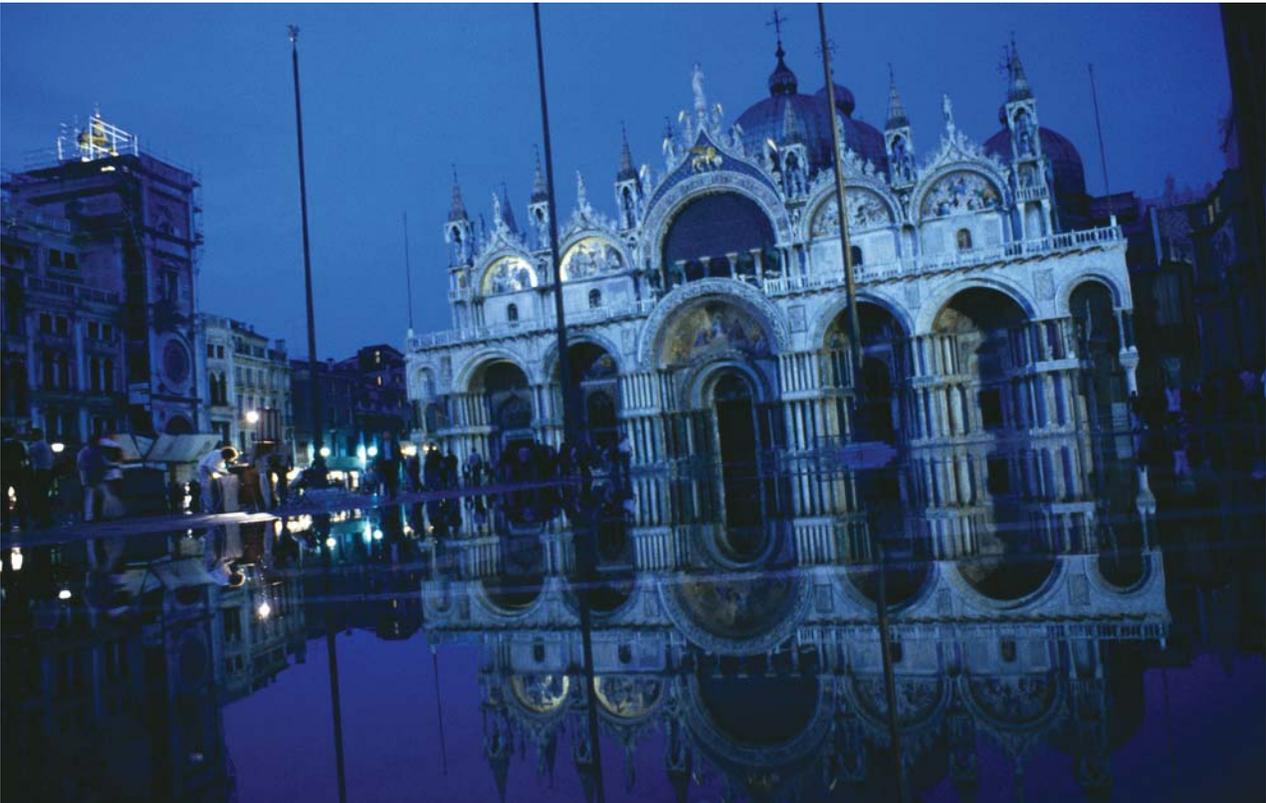
Worldwide, from 1992 to 2001, there were 2,257 reported extreme weather events, including droughts/famines, extreme temperature, floods, forest/scrub fires, cyclones and windstorms. The most frequent natural weather disaster was flooding (43% of 2,257 disasters), killing almost 100,000 people and affecting regions with more than 1.2 billion people (EM-DAT/CRED 2005).

Floods are the most common natural disaster in Europe. During the past two decades, several extreme

San Marco Square, Venice, Italy

floods have occurred in Central European rivers, including the Rhine, Meuse, Po, Odra and Wisla, culminating in the disastrous August 2002 flood in the Elbe River basin and parts of the Danube basin. Flood damages of the magnitude seen in the August 2002 Elbe flood exceeded levels not seen since the 13th century, reaching a peak water level of 9.4 meters (31 feet) (Commission of the European Communities 2002). The 2002 flooding in Central Europe was of unprecedented proportions, with scores of people losing their lives, extensive damage to the socioeconomic infrastructure, and destruction of the natural and cultural heritage (Commission of the European Communities 2002). Germany, the Czech Republic and Austria were the three countries most severely affected. Heavy and widespread precipitation started on 6 August in eastern and southern Germany, Austria, Hungary and in the southwest Czech Republic (Munich Re NatCat Service). Flood waves formed on several major rivers, including the Danube, Elbe, Vltava, Inn and Salzach, with extremely high water levels causing widespread flooding in surrounding low-lying areas.

The regions affected included those above, plus France, northern and central Italy, northeast Spain, the Black Sea coast and Slovakia. It was estimated that 80-100 fatalities resulted from drowning (Munich Re NatCat



San Marco Square now floods many times each year.  
Image: Corbis

Service). Since 2002, severe floods have continued to affect Europe. Parts of the UK have suffered repeated flooding (see Foresight Commission Report discussed below). In the summer of 2005, following a deep drought across central and southern Europe, heavy rains led to severe floods, killing over 45 persons and causing extensive damage. Switzerland was heavily affected.

## THE ROLE OF CLIMATE

The Third Assessment Report of the IPCC concluded that by 2100 the general pattern of changes in annual precipitation over Europe would mean widespread increases in northern Europe (between +1 and +2% per decade), smaller decreases across southern Europe (maximum -1% per decade), and small or ambiguous changes in central Europe (that is, France, Germany, Hungary; Kundzewicz and Parry 2001). The climate change projections suggest a marked contrast between winter and summer patterns of precipitation change. Most of Europe is projected to become wetter during the winter season (+1 to +4% per decade), with the exception of the Balkans and Turkey, where winters are projected to become drier. In summer, there is a projected strong gradient of change between northern Europe (increasing precipitation by as much as 2% per decade) and southern Europe (drying as much as 5% per decade).

The European project PRUDENCE used a high-resolution climate model to quantify the influence of anthropogenic climate change on heavy or extended summer time precipitation events lasting for one to five days. These types of events historically have inflicted catastrophic flooding (Christensen and Christensen 2003). During the months of July to September, increases in the amount of precipitation that exceed the 95th percentile are projected to be very likely in many areas of Europe, despite a possible reduction in average summer precipitation over a substantial part of the continent. Consequently, the episodes of severe flooding may become more frequent even with generally drier summer conditions. Changes in overall flood frequency will depend on the generating mechanisms — floods that are the result of heavy rainfall may increase while those generated by spring snowmelt and ice jams may decrease.

When drought precedes heavy rains, dry soils set the stage for extensive flooding. In addition, arid conditions mean less absorption and recharge of aquifers. Thus swings of weather from one extreme to the other can have the greatest immediate consequences and affect long-term vulnerabilities.

## HEALTH AND ECOLOGICAL IMPACTS

The health impacts from the 2002 European floods included 82 known drownings, several infectious disease outbreaks and reports of extensive anxiety and depression (Hajat et al. 2003).

### EFFECTS ON DRINKING WATER QUALITY

Private water wells and open drinking-water reservoirs are particularly vulnerable to contamination from floods, but other types of public water systems can also be affected. This can lead to an array of gastrointestinal infections.

Outbreaks of shigella dysentery were reported after the 2002 floods in Europe (Tuffs and Bosch 2002). Also, the Russian Federation reported outbreaks in several territories of acute enteric infections and viral hepatitis A (Kalashnikov et al. 2003).

Previous floods in Europe have been associated with outbreaks of noroviral, rotaviral and campylobacter infections (Kukkula et al. 1997; Miettinen et al. 2001).

### RODENT-BORNE INFECTIONS AND OTHER ZONOSSES

Outbreaks of leptospirosis — transmitted through contact with animal urine or tissue or water contaminated by infected animals — were associated with the floods in 2002 when rodents fled their flooded burrows and moved closer to human dwellings (Mezentsev et al. 2003). (Leptospira outbreaks also followed the 1997 spring floods in the Czech Republic and the Russian Federation; Kriz 1998; Kalashnikov et al. 2003.) Another zoonosis associated with the 2002 floods was rabbit-borne tularemia (Briukhanov et al. 2003).

## MOSQUITO- AND SOIL-BORNE DISEASES

Mosquito populations flourish in the aftermath of floods. Surveillance of the population in the flooded parts of Czech Republic after the 1997 floods detected the first cases of West Nile virus to occur in Central Europe (Hubalek et al. 1999).

An outbreak of Valtice fever (caused by Tahyna virus) occurred in the Czech Republic after the 2002 floods (Hubalek et al. 2004). There is the potential for other mosquito-borne disease outbreaks in Europe after flooding, including Sindbis and Batai viruses, and the newly emerged Usutu virus of the same family as West Nile (Weissenböck et al. 2002; Buckley et al. 2003).

In addition, outbreaks of anthrax (soil-based) have been associated with floods in the Russian Federation (Buravtseva et al. 2002).

Floods also flush toxic chemicals and heavy metals into soils, aquifers and waterways. Many pesticides and petrochemicals are persistent organic pollutants that can be carcinogens and suppress the immune system. Heavy metals — such as mercury and cadmium — can cause long-term cognitive and developmental delays. The impacts on wildlife can also be debilitating. These health and ecological issues are under investigation by the Czech Republic and the Russian Federation.

## MENTAL HEALTH

The mental health impacts of flooding stemming from the losses can be devastating for some and last long past the event itself for others (Bennet 1970; Sartorius 1990). A study in the US (Phifer et al. 1988) found that men with low occupational status and individuals 55-64 years of age were at significantly high risk for psychological symptoms. A study in the Netherlands on the health and well-being of people six months following a flood found that 15-20% of children had moderate to severe stress symptoms and 15% of adults had very severe symptoms of stress (Becht et al. 1998). A UK study found a consistent pattern of increased psychological problems among flood victims in the five years following a flood (Green et al. 1985).

## ECONOMIC DIMENSIONS

Floods often cause major infrastructure damage, including disruption to roads, rail lines, airports, electricity supply systems, water supplies and sewage disposal systems. The economic consequences are often greater than indicated by the physical effects of floodwater coming into contact with buildings and their contents. The economic damages can affect development long after the event. Damage to agricultural land, for example, can cause immediate crop damage and affect food production in subsequent years via contamination of soils or loss of topsoil. The implications for the insurance sector may vary from country to country, region to region, depending on government health insurance plans and what private insurers cover.

Floods should be regarded as multi-strike stressors, with the sources of stress including: (1) the event itself, (2) the disruption and problems of the recovery period, and (3) the worry and anxiety about the risk of recurrence of the event (Tapsell et al. 2003). The full impact of a flood often for many affected is not appreciated until after people's homes have been put back in order. The lack of insurance may exacerbate the impacts of floods (Ketteridge and Fordham 1995).

The majority of economic losses in 2002 were public facilities such as roads, railway lines, dikes, riverbeds, bridges and other infrastructure. The proportion of insured losses in Germany was about 20% (Munich Re 2003). Prior to German reunification, almost all householders had taken out state insurance against flood and other natural hazards. In the 1990s, the number of people with this insurance declined. In many places, people were not willing to pay for premiums. In contrast, in the Czech Republic the demand for insurance increased following the 1997 floods on the Odra and Morava. Rough cost estimates for the Elbe 2002 flood alone are approximately US \$3 billion in the Czech Republic and over US \$9 billion in Germany (Munich Re 2003). Flooding in France the following year resulted in seven fatalities and US \$1.5 billion in economic losses, of which US \$1 billion was insured (Munich Re 2003).

Table 2.1 Economic Losses in European Nations in Euros from Flooding in 2002

	Economic Losses	Insured Losses (approx.)
Austria	€ 2-3 bn	€ 400 m
Czech Republic	€ 2-3 bn	€ 900 m
Germany	€ 9.2 bn	€ 1.8 bn
Europe	> € 15 bn	€ 3.1 bn

Between June and December 2002 the Euro exchange rate varied, with the lowest rates noted in December 2002 when 1 Euro = 0.93537 USD and the highest rate in June when 1 Euro = 1.068 USD.

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Floods are taking an enormous toll on lives and infrastructure in developed and developing countries. The Foresight Report on Future Flooding commissioned by the UK government (Clery 2004) concluded that the number of Britons at risk from flooding could swell from 1.6 million to 3.6 million, and that the annual damages from flooding could soar from the current annual figure of US \$2.4 billion to about US \$48 billion — 20 times greater — in the coming decades if construction measures are not taken to meet the challenge.

### CCF-II: SURPRISE IMPACTS

Just as with heat waves, the return periods for heavy precipitation and extensive flooding events may decrease markedly in Europe, Asia, Africa, and in the Americas (Katz 1999). Repeated flooding will challenge the recovery capacities of even the apparently least vulnerable nations.

Prolonged, repeated and extensive flooding — along with melting of glaciers — can undermine infrastructure, cause extensive damage to homes and spread molds, inundate and spread fungal diseases in croplands, and alter the integrity of landscapes. Runoff of nutrients from farms and sewage threaten to substantially swell the 150 “dead zones” now forming in coastal waters worldwide (UNEP 2005).

### SPECIFIC RECOMMENDATIONS

Research is needed to better understand the immediate and chronic physical and mental health impacts of floods. Better disease surveillance is needed during and after flooding, especially for long-term psycho/social impacts as a result of great losses and

the need for medical and social support in the immediate aftermath and during the recovery period.

### EARLY WARNING SYSTEMS

Climate forecasting can improve preparation for natural disasters. Specific measures include:

- Movement of populations to higher ground.
- Use of levees and sandbags.
- Organizing boats for transport and rescue.
- Storage of food, water and medicines.

In countries where flood risk is likely to increase, a comprehensive vulnerability-based emergency management program of preparedness, response and recovery has the potential to reduce the adverse health impacts of floods. These plans need to be formulated at local, regional and national levels and include activities to decrease vulnerabilities before, during and after floods.

### GENERAL MEASURES

- Appropriate housing and commercial development policies.
- Transportation systems tailored to protect open space, forests, wetlands and shorelines. (Forests act as sponges for precipitation; riparian (riverside) stands protect watersheds; and wetlands absorb runoff and filter discharges flowing into bays and estuaries.)
- Livestock farming practices (especially Concentrated Animal Feeding Operations or CAFOs) must be regulated and properly buffered (for example, surrounded by wetlands) to reduce wastes discharged into waterways during floods (see Townsend et al. 2003).
- Insurance policies can directly incorporate the potential for flooding, especially where it has previously occurred, to reduce the number of people and structures “in harm’s way.”
- Economic and social incentives are needed to resettle populations away from flood plains.

Table 2.2 Direct and Indirect Health Effects of Floods

**Direct effects**

Causes	Health Implications
Stream flow velocity; topographic land features; absence of warning; rapid speed of flood onset; deep floodwaters; landslides; risk behavior; fast flowing waters carrying boulders and fallen trees	Drowning Injuries
Contact with water	Respiratory diseases; shock; hypothermia; cardiac arrest
Contact with polluted water	Wound infections; dermatitis; conjunctivitis; gastrointestinal illness; ear, nose and throat infections; possible serious waterborne diseases
Increase of physical and emotional stress	Increase of susceptibility to psychosocial disturbances and cardiovascular incidents

**Indirect effects**

Causes	Health Implications
Damage to water supply systems; sewage and sewage disposal damage; insufficient supply of drinking water; insufficient water supply for washing	Possible waterborne infections (enterogenic <i>E. coli</i> , shigella, hepatitis A, leptospirosis, giardiasis, campylobacter), dermatitis and conjunctivitis
Disruption of transport systems	Food shortage; disruption of emergency response
Underground pipe disruption; dislodgement of storage tanks; overflow of toxic-waste sites; release of chemicals; Rupture of gasoline storage tanks may lead to fires	Potential acute or chronic effects of chemical pollution
Standing waters; heavy rainfalls; expanded range of vector habitats	Vector-borne diseases
Rodent migration	Possible diseases caused by rodents
Disruption of social networks; loss of property, jobs and family members and friends	Possible psychosocial disturbances
Clean-up activities following floods	Electrocutions; injuries; lacerations; skin punctures
Destruction of primary food products	Food shortage
Damage to health services; disruption of "normal" health service activities	Decrease of "normal" health care services, insufficient access to medical care

Source: Menne et al., 2000. *Floods and public health consequences, prevention and control measures*. UN, 2000. (MP.WAT/SEM.2/1999/22)

## NATURAL AND MANAGED SYSTEMS



### FORESTS

#### DROUGHT, BEETLES AND WILDFIRES

Paul Epstein  
Gary Tabor  
Evan Mills

#### BACKGROUND

A delicate balance exists between trees, insects and other animals in forested ecosystems. Now, global warming is upsetting that balance and leading to increased tree devastation by insects. Among the most damaging is the spruce bark beetle (*Dendroctonus rufipennis*, Kirby) that primarily attacks Engelmann Spruce trees that grow from the Southwest US to Alaska. The mountain pine bark beetle (*Dendroctonus ponderosa*) is another main pest of pine trees in western North America, and its primary targets are Lodgepole, Ponderosa, Sugar, and Western White Pines. Another species (*Dendroctonus pseudotsugae*, Hopkins) attacks Douglas Firs preferentially. During the past decade, these beetles have caused the destruction of millions of acres of pine trees in Western North America. These infestations, coupled with decades of fire suppression forest management, have increased susceptibility to forest fires from Arizona to Alaska.

Similar infestations are occurring elsewhere in other temperate regions in the US and abroad. The southern pine beetle attacks trees during drought conditions. Two beetle species account for over 90% of the bark beetle infestations in the Great Lakes Region (Haber Kern et al. 2002). In Eurasia, the European spruce beetle (*Ips typographaphus*) does the most damage and attacks both stressed and unstressed trees (Malmstrom and Raff 2000).

Meanwhile, other pests and pathogens are infecting trees. In California, *Phytophthora*, a relative of the opportunistic fungus responsible for the Irish potato famine, is causing "sudden oak death" in trees that may have been weakened by repetitive weather extremes. In the Northeast US, hemlock conifers are being decimated by an aphid-like bug called the

adelgid that is migrating northward with warmer winters (Parker et al. 1998; D. Foster, Harvard Forest, pers. comm., 2005).

#### THE ROLE OF CLIMATE

When weakened by drought and wilted by heat, trees become susceptible to pests (Kalkstein 1976; Mattson and Hack 1987; Boyer 1995). Normally, trees can keep beetle populations in check by drowning them with resin (or pitch) as they attempt to bore through the bark. Trees also allocate sugars to coat and wall off the fungus carried by the beetles (Warring and Pitman 1985). However, drought diminishes resin flow, and penetrating beetles introduce the fungus that causes decay. The beetles then produce galleries of eggs that hatch into larvae that feed on the inner bark and girdle the tree, leading to the tree's death.

While drought stress weakens the hosts (trees), warming simultaneously encourages the pests. With warmer winters, the beetle reproductive cycle shortens, with the result that beetle population growth outpaces that of their predators. Beetle populations can quadruple in a year.

Since 1994, mild winters have cut winter mortality of beetle larvae in Wyoming, for example, from 80% per annum to less than 10% (Holsten et al. 2000). In Alaska, spruce bark beetles are getting in extra generations and their life cycle is accelerating due to warming (Van Sickle 1995). There, they have stripped four million acres of forests on the Kenai Peninsula (Egan 2002). Warming is also expanding the range of beetles. Lodgepole Pines are the preferred target of the mountain pine bark beetle; since 1998, the beetles have attacked Whitebark Pine stands that grow at higher elevations (8,000 feet or higher) (Stark 2002; Stark 2005).

The cumulative effect of the multi-year drought in the US Southwest from 1996-2003 and the series of warm, dry winters (leaving little snowpack) have facilitated a surge in bark beetle infestations and extensive tree mortality across the region. The prolonged and severe drought directly affected ponderosa pines (*Pinus ponderosa*), piñon-juniper woodlands (*Pinus edulis* and *Juniperus monosperma*) and other trees, and increased rates of soil erosion (Burkett et al. *in press*). In northern New Mexico, piñon pine was severely impacted in 2002 and 2003, with mortality surpassing 90% of mature trees over a widespread area.

## HEALTH AND ECOLOGICAL IMPLICATIONS

Outbreaks of the spruce bark beetle have caused extensive damage and mortality from Alaska to Arizona and in every forest with substantial spruce stands (Holsten et al. 2000). The dead stands provide superabundant kindling for lightning or human-induced wildfires and are particularly vulnerable during drought. Wildfires are hazardous for wildlife, property and people, and they place demands on public health and response systems. While some fires are natural and can have positive effects on vegetation and insect buildup, extensive, cataclysmic-scale wildfires pose immediate threats to firefighters and homeowners, and particles and chemicals from blazes and wind-carried hazes cause heart and lung disease. Some fire by-products (primarily from buildings) are carcinogenic.

Losing forests to fire also threatens the ecological services they provide: a sink for carbon dioxide, a source of oxygen, catchments ("sponges") for flood waters, stabilizers of soils, habitat for wildlife and, via extensive watersheds, clean water. As sources of evapotranspiration (evaporation, and transpiration through leaves) and cloud formation, forests are integral to local climate regimes and to the global climate system. The resilience of large areas of boreal spruce forests that have succumbed to beetle infestations, with resulting large-scale diebacks and fire, are not well understood.

Figure 2.22 Spruce Trees



*Dead stands of spruce trees infested with bark beetles.  
Image: Natural Resources Canada, Canadian Forest Service*

### Hemlock Woolly Adelgid

Woolly adelgid poses a risk to New England forests today. This aphid-like bug has already infected Eastern Hemlock trees in Connecticut, Rhode Island and, Massachusetts, and has moved into southern New

Hampshire. It is moving north with each warm winter. Those trees in Boston's historic Arboretum, designed by Frederick Law Olmstead, have been drastically culled to try to control the infestation.

Eastern Hemlock conifers play unique ecological roles. Hemlocks colonize poor soils and scramble to the crests of mountains. Their arbors are umbrellas for resting deer in winter and the pine needles they shed nourish fish in the deep forest streams they line. When stands of Hemlocks die, their needles add large amounts of nitrogen to the streams and tributaries, and the impacts of their loss is under intense study (Orwig and Foster 2000; Snyder et al. 2002; Ross et al. 2003).

Figure 2.23 Hemlock Woolly Adelgid



*Image: Dr. Mark McClure, CT Agricultural Experiment Station*

## ECONOMIC DIMENSIONS

According to the US Department of Agriculture Forest Service (Holsten et al. 2000), more than 2.3 million acres of spruce forests were infested in Alaska from 1993 to 2000 and the infestation killed an estimated 30 million trees per year at the peak of the outbreak. The Kenai Peninsula in Alaska, Anchorage's playground, is a devastated forest zone. In Utah, the spruce beetle has infested more than 122,000 acres and killed over 3,000,000 spruce trees. The losses have amounted to 333 million to 500 million board feet of spruce saw timber annually. Similar losses have been recorded in Montana, Idaho and Arizona, with estimates of over three billion board feet lost in Alaska, and the same in British Columbia.

In British Columbia, nearly 22 million acres of Lodge pole pine have become infested — enough timber to build 3.3 million homes or supply the entire US housing market for two years (The Economist 9 Aug 2003). In the summer and fall of 2003 the wildfires cost more than US \$3 billion (Flam 2004). The loss of tree cover

created unstable conditions conducive to mudslides and avalanches in subsequent seasons, and these caused property damages and the loss of life.

The implications of the forest changes and tree infestations include losses for several industries: food industries (for example, citrus); tourism, due to reduced scenic quality; maple syrup production; property damage; and business interruptions from wildfires; loss of hydroelectric power from degradation of watersheds; constraints on areas suitable for development, and vulnerability to landslides due to loss of forests and erosion caused by the fires and fire-control activities.

Figure 2.24 Bark Beetles



Bark beetles can bore through spruce tree bark when drought dries the resin that forms its natural defense.  
Image: Rick Delaco, Ruidoso Forestry Department

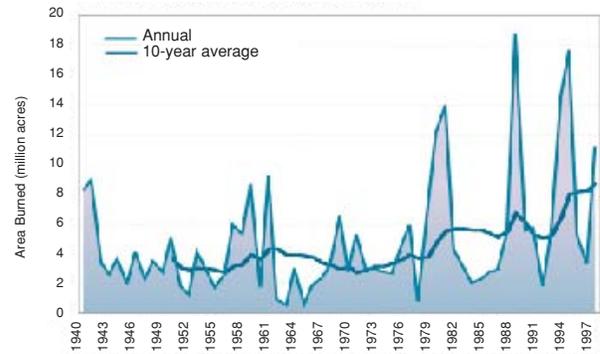
## WILDFIRES

Wildfire is an important outcome of the dynamics of climate and forest health. Climate-related influences include drought, reduced fuel moisture content, changes in wind patterns, shifts in vegetation patterns, and increased lightning (an important source of ignition).

Consequences for humans include the costs of fire suppression, property loss, damage to economically valuable forests (some of which are insured), and adverse impacts on respiratory health arising from increased particulates introduced into air-sheds during fires. As seen in the winter following the large Southern California wildfires of 2003, there can be important indirect impacts, also exacerbated by climate change, such as severe floods and mudflows that arise when torrential rains fall on denuded forestlands.

A distinct upward trend in wildfire has been observed, as measured in terms of average number of acres of Northern boreal forest burned (a doubling since the 1940s) and peak years (a fourfold increase since the 1940s).

Figure 2.25 Annual Area of Northern Boreal Forest Burned in North America



Source: National Assessment of Climate Change: Impacts on the United States.

According to the Insurance Services Office (1997), wildfires are a pervasive insurance risk, occurring in every state in 1996. Wildfires consume an average of 5 million acres per year across the United States. Between 1985 and 1994, wildfires destroyed more than 9,000 homes in the United States at an average insured cost of about US \$300 million per year. By comparison, this was triple the attributable number of homes lost during the three-decade period prior to 1985. Some of this increase is attributed to new home developments in high-risk areas.

The Oakland/Berkeley Tunnel Fire of 1991 was a poignant example of the enormous damage potential of even a single wildfire. The third costliest fire in US history, it resulted in US \$2.4 billion in insured losses (at 2004 prices; Swiss Re 2005a), including the destruction of 3,400 buildings and 2,000 cars (ISO 1997). Added to this were extensive losses of urban infrastructure, such as phone lines, roads and water systems. The insured losses from this single fire were twice the cumulative amount experienced nationwide during the previous 30 years. Swiss Re (1992) and Lloyd's of London pointed to global climate changes as one possible factor influencing the degree of devastation wrought by this and subsequent wildfires.

The total US losses from catastrophic wildfires (a subset of the total defined in terms of events tabulated by the Property Claims Services) was US \$6.5 billion (US \$ 2004) between 1970 and 2004, corresponding to an average insured loss of just over US \$400 million per fire (Insurance Information Institute).

– E.M.

## THE 1997/98 EL NIÑO EVENT

Concerns over the fire-related consequences of global warming were rekindled in 1998 by the impacts of the El Niño of 1997/98, the strongest of the 20th century. This was part of the anomalous period from 1976-98 with an increased frequency, intensity and duration of El Niño events, based on records dating back to 1887. The powerful impact that climatic anomalies can have was demonstrated after droughts linked to El Niño were followed by widespread, devastating fires in Southeast Asia and Brazil, each taking enormous tolls in terms of acute and chronic respiratory diseases. In the US, Florida experienced a rash of wildfires.

- In Malaysia, there was a two-to-threefold increase in outpatient visits for respiratory diseases, as winds carried plumes thousands of miles.
- In Indonesia, 40,000 were hospitalized and losses in terms of property, agriculture and disrupted transport were estimated to be US \$9.3 billion (Arnold 2005).
- In Alta Floresta, Brazil, there was a twentyfold increase in outpatient visits for respiratory diseases.
- In Florida, US, there was a 91% increase in emergency visits for asthma, 132% increase in bronchitis and 37% increase in chest pain.

– P.E.

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Continued warming favors more fungal and insect of forests, and more harsh weather will further weaken tree defenses against pests. Meanwhile, land-use changes as a result of human activities and spreading wildfires can disrupt communities of predators and prey (for example, birds and leaf-eating caterpillars) that have co-evolved and keep populations of pests in check. The ecological implications for essential forest habitat and forest functions (water supplies for consumption, agriculture and energy; absorbing pollutants; drawing down carbon; and producing oxygen) will continue to deteriorate.

Figure 2.26 Rising CO<sub>2</sub> and Wildfires

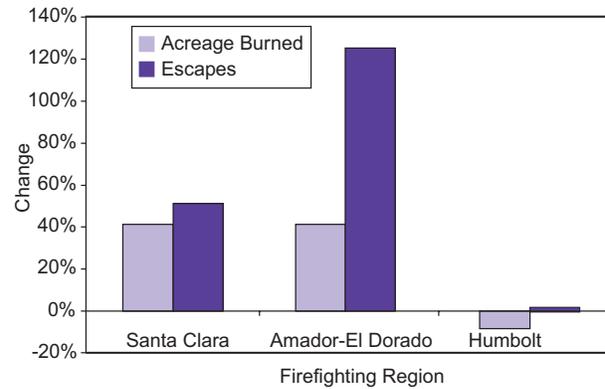


Chart shows results for contained wildfires (acres burned) as well as catastrophic “escaped” fires (number of fires) under a double CO<sub>2</sub> scenario for three major climate and vegetation zones in California. Some subregions exhibited up to a four fold increase in damages. Results calculated by coupling climate models with California Department of Forestry wildfire models, assuming full deployment of existing suppression resources.  
Source: Torn et al. 1998

Northern California forestry services have coupled California Department of Forestry wildfire models with the Goddard Institute for Space Sciences general circulation model of global climate (Torn et al. 1998; Fried et al. 2004). The regions studied include substantial areas of wildlands that interface with urban areas on the margins of the San Francisco Bay area, the Sacramento metropolitan area, and the redwood region's urban center in Eureka. According to this analysis, climate change will be associated with faster burning fires in most vegetation types, resulting in more than a doubling of catastrophic escaped fires under a doubled CO<sub>2</sub> environment. (see figure 2.25). The results include full use of existing fire suppression resources, but exclude the impacts of several important factors, such as beetle infestations, increased lightning activity (the primary cause of wildfire ignitions) and shifts in post-fire plant regimes towards more flammable vegetation types (typically grasses).

Empirical data combined with predictive modeling in British Columbia, performed by the Canadian Forest Service, demonstrate that climate change is eroding the ecological barriers (non-forested prairies and the high elevations of the Rocky Mountains) that once prevented northward expansion of the mountain pine beetle. Adjacent boreal forests in northern Alberta and Saskatchewan, which are populated by susceptible jack pine (*Pinus banksiana*, Lamb) may serve as the next large-scale emergence zone of the beetle advance (Furniss and Schenk 1969; Safranyik and Linton 1982; Cerezke 1995; Carroll et al. 2003; Alberta Sustainable Resource Development 2003).

Climate research has already identified profound impacts of global warming on the ecological integrity of North America's vast boreal forest. Expansion by the beetle into new habitats as global warming continues will provide it a small, continual supply of mature pine, thereby maintaining populations at above-normal levels for some decades into the future. The bark beetle outbreak accelerates the time scale of change significantly.

## EXPANDING RANGE OF SPRUCE BARK BEETLES

Historically, mountain pine beetle populations have been most common in southern British Columbia. Non-forested prairies and the high elevations of the Rocky Mountains have contributed to confining it to that distribution. With the substantial shift by mountain pine beetle populations into formerly unsuitable habitats during the past 30 years, it is likely that the beetle will soon overcome the natural barrier of high mountains as climate change proceeds. Perhaps, as evidence of this shift in recent years, small but persistent mountain pine beetle populations have been detected along the north-eastern slopes of the Rockies in Alberta — areas in which the beetle has not been previously recorded (Alberta Sustainable Resource Development 2003). The northern half of Alberta and Saskatchewan is forested by jack pine, *Pinus banksiana*, Lamb, a susceptible species (Furniss and Schenk 1969; Safranyik and Linton 1982; Cerezke 1995) that may soon come in contact with mountain pine beetles. Indeed, with a conservative increase in average global temperature of 2.5°C (4.5°F) associated with a doubling of atmospheric CO<sub>2</sub>, Logan and Powell (2001) predict a latitudinal shift of more than 7°N in the distribution of thermally suitable habitats for mountain pine beetles.

## CCF-II: SURPRISE IMPACTS

Rapid, widespread climate- and disease-induced forest dieback is a plausible scenario for forests in many regions. Tropical rainforests are already losing ground due to logging, road-building, land-clearing for agriculture, fires purposely set for farming and shifts in the regional hydrological regime that accompany the loss and fragmentation of forests.

The woodlands in the southwest US are increasingly vulnerable to large-scale diebacks. Drought kills trees directly via collapse of the circulatory systems within their trunks and the stems (Allen and Breshears, *in press*). Populations of insect herbivores can “explode” when food becomes more available as drought weakens and

kills trees. Multiplying bark beetle populations then kill more trees, leading to further increases in beetle populations (Carroll et al. 2004). Bark beetles selectively kill large, slow growing trees; thus the process alters the size and age diversity of forests, rendering them ever more vulnerable to parasitism and disease (Swetnam and Betancourt 1998). Reduced ground cover also triggers nonlinear increases in soil erosion rates (Davenport et al. 1998; Wilcox et al. 2003).

Changes in patterns of disturbances from fire, insect outbreaks and soil erosion could produce rapid and extensive reduction in woody species globally, as diebacks outpace forest regrowth (Allen and Breshears 1998; IPCC 2001c; Allen and Breshears *in press*). As forests and shrubs are the primary terrestrial carbon sink, extensive fires and losses will add substantially to the atmospheric accumulation of carbon dioxide, adding to accelerating global warming.

## SPECIFIC RECOMMENDATIONS

Unfortunately, little can be done to directly control bark beetles. Selectively removing trees or spraying pesticides at early stages can help limit spread, but signs of infestations are often not recognized until the late stages. Pesticides, which enter ground and surface waters, are minimally effective and must be applied widely long before beetles awaken in the spring. The scale of the bark beetle outbreak in Canada is so extensive that there is more standing dead timber than there is capacity to log the forests.

Note: The clear-cutting form of forest “thinning” benefits the timber industry in the short term, but these practices damage soils, increase sedimentation in watersheds, reduce water-holding capacity and dry up rivers and streams — all increasing subsequent vulnerability to pest infestations, fires and flooding.

Regulation of the trade and movement of plants can help limit the spread of some diseases. This measure is being employed to try to limit the spread of *Phytophthora*.

Costs aside, none of the downstream ‘treatment’ measures ensure success in suppressing beetle populations. Even the best forest practices will be insufficient to stem the damages from drought and proliferation of beetles and most other forest pests and diseases. The forests need moisture, and global warming and climate change-induced shifts in Earth's hydrological cycle pose long-term threats to the health of forests worldwide.



## AGRICULTURE

### CLIMATE CHANGE, CROP PESTS AND DISEASES

Cynthia Rosenzweig  
X.B. Yang  
Pamela Anderson  
Paul Epstein  
Marta Vicarelli

#### BACKGROUND

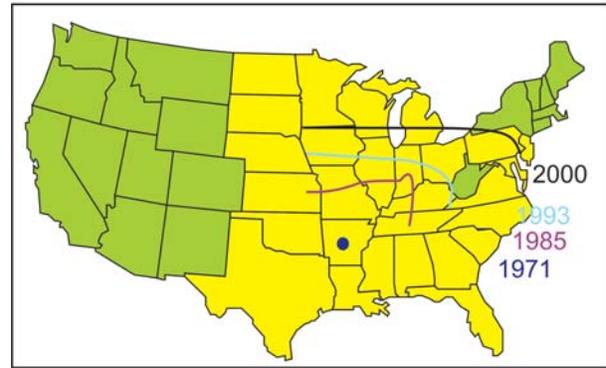
Climate change brings new stresses on the world food supply system. The United Nations' Food and Agricultural Organization (FAO) reports that for the past 20 years there has been a continual per capita decline in the production of cereal grains worldwide. As grains make up 80% of the world's food, world food supply could change dramatically with warming, altered weather patterns and changes in the abundance and distribution of pests. This case study describes the role of climate in agriculture, presents projected impacts on agriculture generated by climate change, examines the associated economic losses and addresses key issues related to risk management for agriculture.

#### THE ROLE OF CLIMATE: CROP GROWTH

**Temperature:** The metabolism, morphology, photosynthetic products, and the "root-to-shoot" ratio of crop plants (a measure of stress) are strongly affected by changes in temperatures. When the optimal range of temperatures is exceeded, crops tend to respond negatively, resulting in a drop in net growth and yield. Vulnerability of crops to damage by high temperatures varies with development stage, but most stages of vegetative and reproductive development are affected to some extent (Rosenzweig and Hillel 1998).

A warmer climate is likely to induce shifts in the optimal zonation of crops. The resulting poleward shift of crop-growing and timber-growing regions could expand the potential production areas for some countries (notably Canada and Russia), though yields might be lower where the new lands brought into production consist of poorer soils. Other constraints on shifts in

Figure 2.27 Soybean Sudden Death Syndrome



This map shows the northern range expansion of soybean sudden death syndrome (*Fusarium solani* f.sp. *glycines*) in North America. Source: X.B. Yang

crop zonation include the availability of water, technology, willingness of farmers to change crops, and sufficiency of market demand.

**Water:** A warmer climate is projected to increase evaporation, and crop yields are most likely to suffer if dry periods occur during critical development stages, such as reproduction. Drought hastens the aging of older leaves and induces premature shedding of flowers, leaves and fruits. Moisture stress during the flowering, pollination and grain-filling stages is especially harmful to maize, soybean, wheat and sorghum. Water is the most serious limiting factor for all vegetation; it takes approximately 1,000 liters of water to produce 1 kg of biomass (Pimentel et al. 2004).

**Extreme weather events:** Extreme meteorological events, such as brief hot or dry spells or storms, can be very detrimental to crop yields. Excess rain can cause leaching and water logging of agricultural soils, impeded aeration, crop lodging, and increased pest infestations. Excess soil moisture in humid areas can also inhibit field operations and exacerbate soil erosion. High precipitation may prohibit the growth of certain crops, such as wheat, that are particularly prone to lodging and susceptible to insects and diseases (especially fungal diseases) under rainy conditions (Rosenzweig and Hillel 1998). Interannual variability of precipitation is already a major cause of variation in crop yields, and this is projected to increase.

#### THE ROLE OF CLIMATE: CROP PESTS, PATHOGENS AND WEEDS

Meteorological conditions also affect crop pests, pathogens and weeds. The range of plant pathogens and insect pests are constrained by temperature, and the frequency and severity of weather events affects the timing, intensity and nature of outbreaks of most organisms (Yang and Scherm 1997).

# LOSSES ASSOCIATED WITH 1993 HEAVY PRECIPITATION AND FLOODS

Losses accounted for in Mississippi River Basin: \$23 billion.

The unaccounted-for health and ecological consequences included:

- Over 400,000 cases of cryptosporidiosis in Milwaukee, with over 100 deaths in immunocompromised hosts, after flooding of sewage into Lake Michigan contaminated the city's clean water supply (Mackenzie et al. 1994).
- Doubling of the size of the Gulf of Mexico "Dead Zone" in 1993, with subsequent retraction, from increased runoff of nitrogen fertilizers after flooding.
- Emergence of hantavirus pulmonary syndrome. Six years of drought in the US Southwest reduced rodent predators, while early and heavy rains in 1993 increased their food sources, leading to 10-fold increase in rodents and the emergence of this new disease (Levins et al. 1993).
- Several cases of locally transmitted malaria in Queens, NY, associated with unusually warm and wet conditions (Zucker 1996).

Milder winters and warmer nights allow increased winter survival of many plant pests and pathogens, accelerate vector and pathogen life cycles, and increase sporulation and infectiousness of foliar fungi. Because climate change will allow survival of plants and pathogens outside their historic ranges, models consistently indicate northward (and southward in the Southern Hemisphere) range shifts in insect pests and diseases with warming (Sutherst 1990; Coakley et al. 1999). About 65% of all plant pathogens associated with US crops are introduced and are from outside their historic ranges (D. Pimentel, pers. comm. 2005), and models also project an increase in the number of invasive pathogens with warming (Harvell et al. 2002).

Sequential extremes can affect yields and pests. Droughts, followed by intense rains, for example, can reduce soil water absorption and increase the potential for flooding,

thereby creating conditions favoring fungal infestations of leaf, root and tuber crops in runoff areas. Droughts, followed by heavy rains, can also reduce rodent predators and drive rodents from burrows. Prolonged anomalous periods — such as the five years and nine months of persistent El Niño conditions (1990-1995; Trenberth and Hoar 1996) — can have destabilizing effects on agriculture production, as has recurrent drought from 1998 to the present in the western US.

Long-term field experiments discussed in the case study of aeroallergens show that weeds respond with greater reproductive capacity (pollen production) to elevated CO<sub>2</sub> (Wayne et al. 2002; Ziska and Caulfield 2000; Ziska et al. 2003), as do some arbuscular mycorrhizal fungi (Wolf et al 2003; Treseder et al. 2003; Klironomos et al. 1997). These changes can also influence crop growth.

## TRENDS IN AGRICULTURAL PESTS

Since the 1970s, the ranges of several important crop insects, weeds, and plant diseases have expanded northward (Rosenzweig et al. 2001). In Asia, the prevalence and distribution of major diseases, such as rice blast, rice sheath blight, wheat scab, wheat downy mildew and wheat stripe rust have changed significantly. Characteristically warm-temperature diseases have increased, while cool-temperature diseases have decreased (Yang et al. 1998) For example, in China, changes in warm-temperature diseases are statistically correlated with changes in average annual temperature from 1950 to 1995 (Yang et al. 1998).

## EXTREMES AND PESTS

- Drought encourages aphids, locust and whiteflies (and the geminiviruses they can inject into staple crops). Some fungi, such as *Aspergillus flavus* that produces aflatoxin, is stimulated during drought and it attacks drought-weakened crops (Anderson et al. 2004).
- Floods favor most fungi (mold) and nematodes (Rosenzweig et al. 2001).

In the Western Hemisphere, plant pathologists have observed new or reemerging crop diseases during the last two decades. Significant expansion of disease ranges in major agriculture crops appears to have started in the early 1970s. Range expansion of the gray leaf blight of corn, caused by the fungus *Cercospora zeae-maydis*, first noticed in the 1970s, has now become the major cause of corn yield loss in the USA (Anderson et al. 2004). Bean pod mottle virus of soybean, vectored by bean leaf beetles, has expanded its damage range from the southern US to the northcentral region, becoming a major yield-limiting factor. The range of soybean sudden death syndrome has expanded similarly (see figure 2.27).

Many emerging diseases have become established as significant threats to major crops. According to a recent survey sponsored by the National Plant Pathology Board of the American Phytopathological Society, new diseases have emerged in almost all the major food crops in the US in the last 20 years. For several crops there are up to four reported new or emerging diseases (Rosenzweig et al. 2001).

## IMPACTS ON HUMAN HEALTH AND NUTRITION

The fungus known as potato late blight was a major cause of the widespread famine that induced the great Irish migration in the 19th century. The 1943 outbreak of rice leaf blight after a flood in Bengal, India, resulted in severe crop loss followed by a famine in which two million people died of starvation.

Undernutrition is a fundamental cause of stunted physical and intellectual development in children, low productivity in adults, and susceptibility to infectious diseases. The United Nations Food and Agriculture Organization (FAO) estimates that in the late 1990s, 790 million people in developing countries did not have enough to eat (FAO 1999). The FAO figure applies to those with protein/calorie malnutrition and omits the 2 billion iron-malnourished people and others who are vitamin- and iodine-deficient (WHO 2004). By this encompassing definition, some 3.7 billion humans are currently malnourished.

Outbreaks of pests, fungi and increased growth of weeds will require the increased use of pesticides (herbicides, fungicides, insecticides). These persistent organic pollutants contaminate surface and underground water supplies and food, and threaten the health of farm workers and consumers.

## ECONOMIC DIMENSIONS

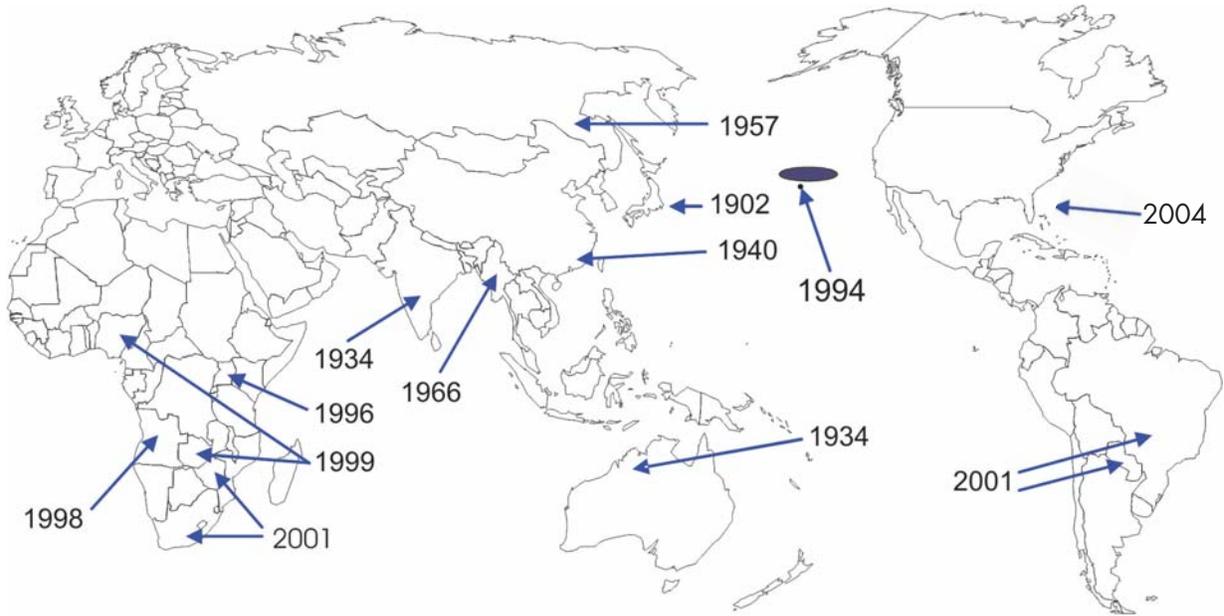
Previous economic estimates of the impacts of climate change on US agriculture are based on model projections of gradual change in temperatures (Adams et al. 1999). Mendelsohn et al. (1999) account for temperature variance in their models and find that, if interannual variation in temperature increases by 25% every month, average farm values fall by about one-third. Similar variation in precipitation decreases farm values only 6%. Notably, these models do not include changes in the timing of seasons nor the overall role of weather extremes. None take into account the impacts of pests, pathogens and weeds associated with warming and the increased variability.

Extreme weather events have caused severe damage for US farmers in the past two decades (Table 2.3 on Page 75) (Rosenzweig et al. 2001). Estimated losses from the 1988 summer drought were on the order of US \$56 billion (1998 dollars) and cost the taxpayers US \$3 billion in direct relief payments. The losses from the 1993 floods in the Mississippi River Valley exceeded US \$23 billion, but this does not include the costs of treating and containing the associated disease outbreaks.

Worldwide, pests cause yield losses of more than 40% of potential crop value (Altaman 1993; Pimentel 1997). For tropical crops such as sugarcane, losses can be as high as 50% of potential yields. Postharvest losses of food (primarily from rodents and mold) amount to about 20%. Taken together, pre-harvest and post-harvest losses from pests amount to about 52% of world food production.

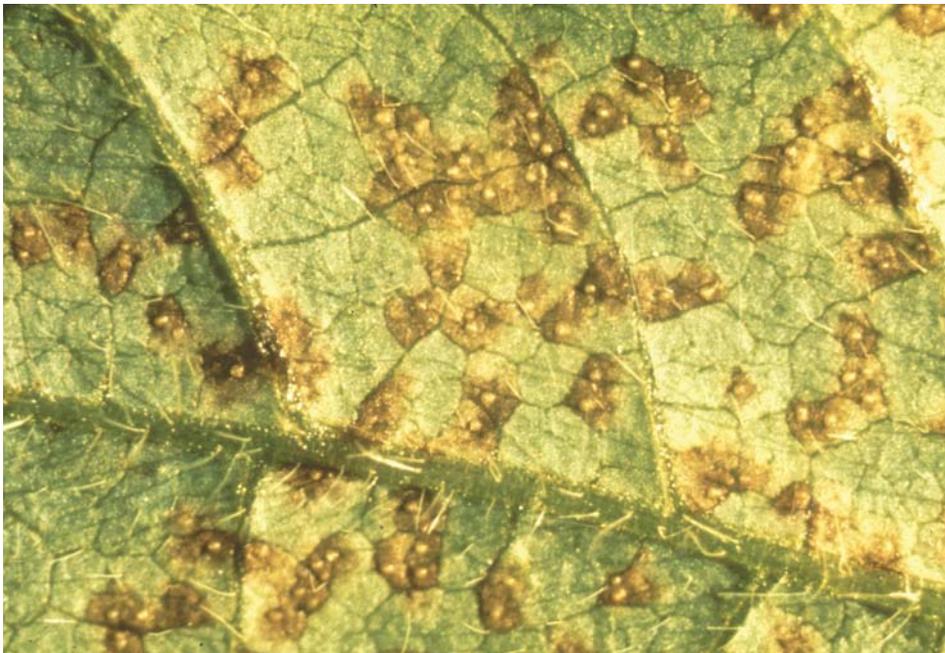
Worldwide there are about 70,000 pests (insects, plant pathogens and weeds) that damage crops. Despite 3 billion kg in pesticides applied per year, costing about US \$35 billion, plus other non-chemical controls, pests destroy more than 40% of all crops with a value of about US \$300 billion per year (Oerke et al. 1995). After world crops are harvested, other pests (insects, microbes, rodents and birds) destroy another 25% of world food. Thus, pests are destroying approximately 52% of all crops despite the use of pesticides and other controls (D. Pimentel, pers. comm. 2005).

Figure 2.28 Soybean Rust Introduction



World map indicating areas where soybean rust (*Phakopsora pachyrizi*) was first reported. Soybean rust is believed to have entered the US with dust transported by Hurricane Ivan in 2004 (Stokstad 2005).  
Source: X.B. Yang

Figure 2.29 Soybean Rust



Soybean rust disrupting leaf growth.

Image: Joe Hennen.  
Botanical Research Institute,  
Fort Worth, TX.

## ECONOMIC IMPACTS OF SOYBEAN DISEASES

Projected losses from introduction of soybean rust into the US were made in the early 1980s (Kuchler et al. 1984). Soybean production in the Americas accounts for over 80% of the soybean produced globally. For many years, soybean prices have been suppressed by the expansion of cropping area in South America, which now produces more soybean than is produced in North America. Expansion of global demand (mainly by Asian countries, especially China) has been offset by the expansion of areas for soybean production in South America. Consequently, soybean prices have fluctuated around US \$5 to US \$6/bushel with the highest being about US \$8/bu and the lowest being below US \$4/bu.

In 2002, US soybean farmers experienced epidemics of Soybean Sudden Death Syndrome (SDS) (see figure 2.27) and various viral diseases, causing nearly US \$2 billion in losses. In the 2003 growing season, outbreaks of Asian aphids and charcoal rot — a fungal root rot disease — occurred in Iowa, Illinois and Minnesota, the three largest soybean producing states, after cool July weather suddenly turned into a record dry August. Yields in these states were 20-28% lower than those in the 2002 season and resulted in record high prices of soybean futures in the US.

The global situation was exacerbated by the introduction of soybean rust into South America, mainly in Brazil and Paraguay (see figure 2.28). Shortly after the disease was reported in 2001 in South America, severe epidemics occurred in the 2003 growing season, resulting in losses of US \$1.3 billion in Brazil alone, despite mass application of fungicides.

In 2004, soybean rust was worse than in 2003. The disease occurred early and, in central and northern Brazil, excessive rains favored its development. Losses in 2004 were over US \$2.3 billion. According to a report presented by Brazilian plant pathologists at World Soybean Research Conference (March 2004), US \$ 750 million worth of fungicides were used to control soybean rust in 2003 and fungicide use has surpassed herbicide use in Brazil.

The year 2004 also brought drought to soybean producing regions in southern Brazil and Argentina, inducing widespread “charcoal rot,” another fungal disease. The estimated yield reduction due to drought and charcoal rot was 30% in southern Brazil (USDA 16 Aug

2004). Such yield reductions in both North and South America have raised the price of soybean from around US \$5/bu in 2003 August to near US \$11/bu for soybean delivered in May 2004. It reached US \$14/bu for a short period in 2004. It is predicted that 30% of soybean producers in Mato Grosso, Brazil, the largest soybean production region in the world, will be out of business in the next several years due to soybean rust (Hiromoto 2004).

Most recently, soybean rust is thought to have been introduced into the US by Hurricane Ivan, one of the four to hit Florida in fall 2004 (Stokstad 2004). The fungal disease rapidly spread to 11 states and it is estimated by the USDA that soybean rust will cost American farmers US \$240 million to US \$2 billion/year within three to five years (Livingston et al. 2004).

Soybean Field



Image: Corbis

Table 2.3 Extreme Weather Events Causing Severe Crop Damage in the US: 1977-2003

Year	Geographical area	Extreme weather event and US losses
1970	U.S. Southern States	Southern corn blight (pest). Total losses: \$56 billion
1977	U.S. Southern States	Drought induced high aflatoxin concentration in corn, costing producers more than \$80 million.
1977	U.S. Corn Belt	Drought disrupted domestic and export corn marketing.
1980	U.S. Central and Eastern regions	Summer drought and heat wave.
1983	U.S. Southern States	Drought induced high aflatoxin concentration in corn costing producers more than \$97 million.
1983	U.S. Corn Belt	Drought disrupted domestic and export corn marketing.
1986	U.S. Southeast	Summer drought and heat wave.
1988	U.S. Central and Eastern regions	Summer drought and heat wave. Congress paid farmers over \$3 billion for crop losses. Total losses: \$56 billion.
1990	U.S. Texas, Oklahoma, Louisiana, Arkansas	Flooding in spring.
1993	U.S. Midwest	Flooding in summer affecting 16,000 square miles of farmland, and damaging crops in over 11 million acres. Crop losses over \$3 billion. Total losses exceeded \$20 billion.
1993	U.S. Southeast	Drought and heat wave in the summer, causing the loss of 90% of corn, 50% of soybean, and 50% of wheat crops. Crop losses over \$1 billion.
1994	U.S. Texas	Severe flooding.
1995	U.S. Southern Plains	Severe flooding.
1995	U.S. Texas, Oklahoma, Louisiana, Mississippi, California.	Severe flooding.
1996	U.S. Pacific Northwest, Appalachian, Mid-Atlantic and Northeast	Severe flooding.
1997	U.S. Northern Plains, Arkansas, Missouri, Mississippi, Tennessee, Illinois, Indiana, Kentucky, Ohio, West Virginia	Severe flooding.
1997	U.S. West Coast	Severe flooding from December 1996 to January

Sources: National Climatic Data Center, NOAA; X.B. Yang, personal communication

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Climate change will affect agriculture around the globe. A changing climate will alter the hydrological regime, the timing of seasons, the arrival of pollinators and the prevalence, extent, and type of crop diseases and pests. Globalization and intensification techniques may also contribute to new configurations of plant-pest relationships that affect cultivated and wild plants.

A warming of 1°C is estimated to decrease wheat, rice and corn yields by 10% (Brown 2002). Warming of several °C or more is projected to alter production significantly and increase food prices globally, increasing the risk of hunger in vulnerable populations (Houghton et al. 2001). Particularly large crop losses become more likely when extreme weather events produce favorable conditions for pest outbreaks.

Climate change can lead to the resurgence of pre-existing pathogens or can provide the conditions for introduced pathogens to thrive. Milder winters and higher overall temperatures will facilitate winter survival of plant pathogens and invasive species, and accelerate vector and pathogen life cycles (foliar fungi, bacteria, viruses) (Anderson et al. 2004).

While global average water vapor concentration and precipitation are increasing, irrigation requirements are projected to increase in some agricultural regions and larger year-to-year variations in precipitation are very likely over most areas (Houghton et al. 2001). These changes will likely lead to increased outbreaks of foliar fungal diseases, such as soybean rust. Warming and increased precipitation and accompanying diseases would increase the use (and costs) of pesticides for certain crops, such as corn, cotton, potatoes, soybeans and wheat (Chen and McCarl 2001).

Models for cereal crops indicate that, in some temperate areas, potential yields increase with small temperature increases, but decrease with large temperature rises. In most tropical and subtropical regions, however, potential yields are projected to decrease under all projected temperature changes, especially for dryland/rainfed regions where rainfall decreases substantially.

The impacts of climate change, therefore, will fall disproportionately upon developing countries and on the poor within all countries, exacerbating inequities in health sta-

tus and access to food, clean water and other basic resources. Shortages in food supply could generate distortions in international trade at regional and global levels, and disparities and disputes could become more pronounced over time (Houghton et al. 2001).

### CCF-II: SURPRISE IMPACTS

The current trajectory for warming and more violent and unpredictable weather could have catastrophic effects on agricultural yields in the tropics, subtropics and temperate zones. Disease outbreaks could take an enormous toll in developing nations, and overuse of pesticides could breed widespread resistance among pests and the virtual elimination of protective predators.

With pests currently causing yield losses over 40% worldwide (Altaman 1993), losses could climb steeply to include the majority of food crops, especially for tropical crops such as sugarcane, for which current annual losses often exceed 50% under today's conditions. With production of the eight most vital foods on the order of US \$300 billion annually, and over 50% growing and stored grains now lost to pests, pathogens and weeds, more warming, weather extremes and pests could drive losses in particularly devastating years well over US \$150 billion per annum. Multi-regional food shortages could lead to political instability.

## SPECIFIC RECOMMENDATIONS

Early warning systems of extreme events can aid in the a) selection of seeds, b) timing of planting, and c) planning for petrol, petrochemical and fertilizer requirements.

Figure 2.30 Healthy Corn Fields



Image: Shaefar Elvira/Dreamstime

General measures to reduce the impacts of weather extremes and infestations include:

- No tillage agriculture.
- Maintaining crop diversity that helps limit disease spread.
- Maintaining flowering plants that support pollinating insects and birds.
- Maintaining trees around plots that serve as windbreakers and provide homes for worm- and insect-eating birds.
- Integrated pest management and organic farming, as toxic chemicals can kill pollinators (birds, bees and butterflies), predators of herbivorous insects (ladybugs and parasitic wasps), and predators of rodents (owls, hawks and eagles).
- Appropriate national and international food policies (subsidies, tariffs, prices) are needed to provide the proper incentives for sustainable agriculture.

**The farming sector can also profitably contribute to climate solutions.** Such measures include:

- Soil and plant biomass carbon sequestration.
- Methane capture for energy generation.
- Plants and animals used to produce biofuels.
- Plants for biodiesel.
- Solar panel arrays.
- Wind farms.

Integrated systems, with a diversity of crops and of surrounding ecological zones, can provide strong generalized defenses in the face of weather extremes, pest infestations and invasive species. The mitigation options to absorb carbon and generate energy cleanly can become a significant part of farming activities and contribute significantly to stabilizing the climate.



## MARINE ECOSYSTEMS

### CASE 1. THE TROPICAL CORAL REEF

Raymond L. Hayes

#### BACKGROUND

Threats to coral reefs constitute one of the earliest and clearest marine ecosystem impacts of global climate change. Coral reefs are in danger worldwide from warming-induced bleaching and multiple emerging diseases. Their decline was first apparent in the early 1980s and reef death has progressed steadily since (Williams and Bunkley-Williams 1990). Approximately 27% of reefs worldwide have been degraded by bleaching, while another 60% are deemed highly vulnerable to bleaching, disease and subsequent overgrowth by macro-algae (Bryant et al. 1998). Mortality of reefs in the Caribbean islands of Jamaica, Haiti and the Dominican Republic is now over 80% (Burke 2004).

This level of impact — with continued ocean warming and pollution — could lead to collapse of the reefs entirely within several decades. While ecological systems can reach thresholds and collapse suddenly, their recovery and reorganization into a new equilibrium could be very slow (Maslin 2000).

Coral reefs provide numerous ecological functions for marine life and serve as physical buffers that protect low-lying tropical islands and coastal zones against storms. The total value of reef-related shoreline protective services in the Caribbean region has been estimated to be between US \$740 million and US \$2.2 billion per year. Depending upon the degree of development, this coastal-protection benefit ranges from US \$2,000 to US \$1,000,000 per kilometer of coastline (Burke and Maidens 2004).

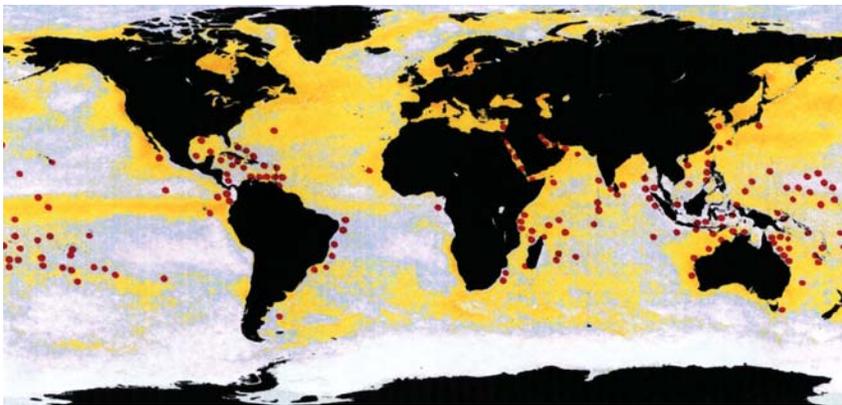
## THE ROLE OF CLIMATE

Reefs are very sensitive to temperature anomalies. Although some coral colonies inhabit deep water and temperate water niches, reef-building corals are restricted to shallow, near-shore waters and to a temperature range of only a few degrees Celsius. Optimal temperature for coral vitality and skeletal production is 25–28°C (McNeil et al. 2004). With annual warm season sea temperature maxima now approaching 30°C, reef-building corals are losing their efficiency for frame construction and repair. When sea temperature persists for a month or more above 30°C (86°F), or reach a 1°C (1.8°F) anomaly above long-term seasonal averages during the warmest season of the year (see map, figure 2.31), bleaching occurs in reef organisms harboring algal symbionts. Also, more frequent and intense extreme events, including hurricanes, cyclones, torrential rainfall and mudslides can cause reef frame breakage, sedimentation, microbial and planktonic proliferation, runoff of chemical pollutants from terrestrial sources, and shore erosion. All of these insults degrade reef ecosystem integrity and coral vitality. Frame damage to coral reefs following storm activity, especially among fragile branching corals and exposed coral mounds, is documented (Nowlis et al. 1997). However, subtle damage to interactive balances within the reef ecosystem may not be as evident and can only be appreciated through physiological data.

Apart from warming, CO<sub>2</sub> causes acidification of the oceans and depletion of calcium from coral reefs could kill all coral organisms by 2065 (Steffan et al. 2004a Orr et al. 2005; Pelejero et al. 2005), though some researchers believe the ocean warming itself may alter this projected outcome (McNeil et al. 2004).

Climate change is the principal agent forcing change in the coastal oceans. Atmospheric warming due to the accumulation of greenhouse gases offers the source of excess heat that rapidly equilibrates in the world's oceans (Levitus et al. 2000). The rate of warming in surface waters exceeds the rate of evaporation of humidity back into the atmosphere. The reverse gradient of warm hypersaline surface water sinks to give reefs exposure to high temperatures. Excessive warming of coastal oceans, especially during the warmest months of the year, coupled with inadequate relief from warming during the coolest months of the year, have pushed the coral reef ecosystems beyond their thermal limit for survival (Goreau and Hayes 1994). In response to warming, marine microbes that are responsible for diseases of reef-building corals also thrive. They proliferate, colonize and invade coral tissues, producing tissue infection and ultimately, coral death.

Figure 2.31 Sea Surface Temperatures and Coral Bleaching



14-year cumulative sea surface temperature anomalies and areas of coral bleaching indicated by red circles. Years with El Niño events and volcanic eruptions have been removed from the data set. Yellow indicates temperatures 1°C above the mean temperature; orange indicates anomalies 2°C above the long-term average.

Source: (Base map) Climate Diagnostics Bulletin, NOAA AVHRR Satellite Database, 1982-2003 and (data) Ray Hayes and Tom Goreau

Physiological stresses on reef organisms are additive. Although reef changes are triggered by elevated temperature, several other factors compound the negative effects upon the ecosystems. Pollution from industrial, agricultural, petrochemical and domestic sources, sedimentation from shoreline erosion, daytime penetration of intense ultraviolet radiation, and hyposalinity from freshwater runoff during times of extreme rainfall impose added environmental stresses that impede recovery of the compromised reef.

Caribbean reefs are now subject to annual episodes of bleaching and persistent expression of diseases (see figure 2.31). The imminent collapse of Jamaica's reefs and their overgrowth of macroalgae was already apparent by 1991 (Goreau 1992) as a result of bleaching stress (Goreau and Hayes 2004), mass mortality of sea urchins (Lessios 1984), overharvesting of reef fishes (Jackson et al. 2001), and excess nutrient-loading with nitrates and phosphates released from the land sources (Hughes et al. 2003).

The collapse of reefs means the loss of net benefits that vary in economic value depending upon the degree of coastal development. However, in Southeast Asia the total loss is estimated to represent an annual value of US \$20,000-151,000 per square kilometer of reef (Burke 2002). This estimate is based upon an assessment of benefits derived from fisheries, coastal protection, tourism and biodiversity.

## CORAL DISEASES

In addition, all species of keystone reef-building corals have suffered mounting rates of mortality from an increasing assortment of poorly defined emerging bacterial diseases. Within the last three decades, coral colonies have become hosts to various microbes and have demonstrated limited capacity to either resist microbial colonization and invasion or defend against tissue infection and premature death (Harvell et al. 1999; Sutherland et al. 2004).

Bacteria normally live in dynamic equilibrium within the surface mucous layer secreted by corals. This relationship between bacteria and coral mucus is one of mutual benefit, since tropical waters are nutrient poor and incapable of sustaining bacterial metabolism. Coral mucus serves as a source of nutrition for these bacteria, and the bacteria, in turn, provide protection to corals from predators. However, once bacteria colo-

nize, invade and infect the coral tissue, that relationship of mutualism shifts to parasitism. The corals, lacking other effective defense mechanisms against infection, are rapidly overgrown by macroalgae, as well as bacteria and other microbes.

The most prevalent signs of infection are discoloration, detachment from the skeleton, and loss of tissue integrity. Discolorations may be due to bacterial growth (for example, black band), loss of algae (for example, bleaching, coral pox), or local accumulation of pigment (for example, yellow band, dark spot). Detachment of tissue from the skeleton represents dissolution of anchoring filaments and/or solubilization of the aragonitic (a calcium compound) skeleton itself (for example, coral plague). Tissue necrosis is slowly progressive and usually includes a patterned loss of epithelial integrity (for example, white band).

## HEALTH AND ECOLOGICAL IMPACTS

Decline in the health and integrity of coral reefs has multiple implications for sea life and for the coastal zone bordering low-lying tropical lands. Declines and loss will decrease their function as nurseries for shellfish and finfish (approximately 40% of stocks worldwide), and affect the lives and livelihoods for communities that depend on fishing for consumption and commercialization. The disruption of reefs as shoreline barriers allows salt water intrusion and salinization of groundwater. This can lead to hypertension in humans and decreased soil fertility for agricultural production (further affecting health and nutrition). Reefs are also becoming reservoirs for microbial pathogens that can contaminate the food chain, and are associated with human health risks from direct contact with microbe-laden coastal waters (Epstein et al. 1993; Hayes and Goreau 1998).

# HARMFUL ALGAL BLOOMS

Figure 2.32 Red Tide



Image: P.J.S. Franks/Scripps Institution of Oceanography

Marine red tides or harmful algal blooms (HABs) are increasing in frequency, intensity and duration worldwide, and novel toxic organisms are appearing (Harvell et al. 1999). Cholera and other bacteria harmful to humans are harbored in the phyto- and zooplankton that form the basis of the marine food web. The increase in nitrogenous wastes (fertilizers, sewage and aerosolized nitrogen) provides the substrate for HABs, while warm, stagnant waters and runoff of nutrients, microorganisms and toxic chemicals after floods can trigger large blooms, sometimes with toxin-producing organisms (Epstein et al. 1993).

Most biological toxins from red tides affect the nervous system. The effects range from temporary tingling of the lips, to headaches, change in consciousness, amnesia and paralysis. Repeated exposure could possibly lead to chronic fatigue, and the role of biotoxins

in suppressing the immune systems and thus increasing susceptibility to infections and cancers needs further study.

Brown tides cause hypoxia and anoxia, and are contributing to the over 150 “dead zones” being reported in bays and estuaries around the world (Rupp and White 2003 UNEP 2005), as well as losses of sea-grass beds, nurseries for shellfish (Harvell et al. 1999).

Mangroves — whose dropped leaves feed fish and whose roots hide them — are being removed for aquaculture and coastal development. Mangroves are also threatened by sea level rise. Loss of wetlands and coral reefs, sea level rise and greater storm surges threaten beaches, roads, homes, hotels, island fresh-water “lenses,” nutrition and livelihoods.

The 2005 HAB outbreak of *Alexandrium fundyense* in New England was associated with heavy rains in May and two nor’easters in June. The nor’easters (spawned by high pressure systems over cool fresh North Atlantic waters) blew the blooms against the coast and brought cold upwelling water with additional nutrients. The large 1972 bloom in New England of the dinoflagellate, *Alexandrium tamarense*, bearing saxitoxins causing paralytic shellfish poisoning, first appeared near the mouth of rivers after a drought ended with a hurricane. The extensive 2005 bloom in the Northeast — affecting tourism, fisheries, livelihoods, event planners and restaurants — cost US \$3 million a week and could seed cysts along many square miles of coastline, setting the stage for harmful algal blooms in subsequent years.

A red tide persisting at least nine months off Florida’s west coast has taken a large toll on fisheries, livelihoods and tourism (Goodnough 2005).

— P.E.

## ECONOMIC DIMENSIONS

Table 2.4 provides a global environmental economic estimate of the potential new benefit streams from coral reefs per year and the net present value (NPV) of the world’s coral reefs in billions of US dollars. This analysis is based upon a 50-year extrapolation at a discount rate of 3% (Cesar et al. 2003).

Table 2.4 The “Value” of Coral Reefs

GOODS / SERVICES	AMOUNT (in US \$BILLION)
Fisheries	5.7
Coastal Protection	9.0
Tourism / Recreation	9.6
Aesthetics / Biodiversity	5.5
TOTAL	29.8
NPV	797.4

Source: Cesar et al. 2003

There are many questions concerning this cost-benefit accounting methodology, especially the true nature of the benefits (for example, medicines derived from reef-dwelling organisms, which can generate billions of dollars in revenue), and the connected costs and multiple intangibles included in the cost-benefit analyses. In addition, benefits can accrue over time and alter the value of natural assets. It is questionable if these figures accurately portray the full evaluation of a threshold event, such as the collapse of reefs worldwide.

## SOCIO-ECONOMICS OF THE 1997-98 CORAL REEF BLEACHING EPISODE IN THE INDIAN OCEAN

In the short term, the most dramatic socio-economic impacts from the 1997-98 mass bleaching event were estimated losses to reef-dependent tourism. These losses were developed for the diving destinations at Palau, El Nido, Palawan, the Philippines and other sites in the Indian Ocean region.

Table 2.5 Losses from 1997-98 Bleaching (US \$Millions)

Country	Total Losses
Zanzibar	7.4
Mombasa	35.1
Maldivas	22.0
Sri Lanka	2.2
Philippines	29.6
Palau	0.4

Source: Westmacott et al. 2000

The manifestation of the losses shown in the table above is multidimensional and includes: a) impacts on tourist destination choice, which results in lost visitation and therefore a total loss of tourism revenue; b) impacts on choice of activities pursued, which may cause reduced coral reef-related revenue; and c) reductions in tourist satisfaction with the diving experience as a result of degraded reef conditions.

The implication is that impacts of coral bleaching on tourism depend upon whether diving destinations can maintain their status and reputation, even in the face of reef degradation, through promotion of other underwater attractions. Impacts upon the diving industry might be reduced by diverting diver attention to other interests, such as shipwrecks or even the documentation of coral bleaching per se. However, such tactics may be

risky and non-sustaining. For example, resorts in El Nido shifted market segments away from divers to honeymooners in response to reef degradation, resulting in a significant loss of US \$1.5 million annually.

Studies undertaken in the Indian Ocean region in response to the 1997-98 bleaching event provide empirical documentation and estimates of the impact of a single catastrophic episode of coral reef bleaching. The upper end of the cost estimate is US \$8 billion, depending on the ability of the reefs to ultimately recover.

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Global warming, with inadequate winter cooling, will continue to heat sea surfaces, especially across the tropics. The full impact of such temperature increases on the vitality of coral reef ecosystems will depend upon the nature of other human-induced changes and the cumulative stresses placed upon reef ecosystems. Overall, the projected warm seasonal disruption of symbiosis in reef-building corals will reduce the growth in mass of the inorganic reef frame.

With weakened frames, the susceptibility of coral reefs to physical damage during storms increases, while the capacity for self-repair diminishes. Thermal stress and bleaching also disrupts food production and energetics within reef-building corals, retarding the generation of mature gametes for sexual reproduction and reducing the coral's abilities to resist predation. With time, reefs become fragile and less able to protect shores against storm surges.

Global warming, meanwhile, would stimulate proliferation, colonization, random mutation and host invasion of marine microbes. The coral's already compromised defenses against predation would be further challenged by an invigorated assortment of micro-predators with limitless strategies for penetrating coral tissues.

## IMPACT ON FISHERIES

Population reductions have been predicted for species that inhabit reefs for at least part of their life cycle or that prey on smaller reef fish. Changes in fish abundance would vary by species, shifting the net composition of reef fish populations toward herbivores. Such a shift would negatively impact fishermen, as herbivores are lower in value than other species. When bleaching is superimposed on reefs that are already overfished, reductions in overall reef fish populations would not be expected, since herbivores would have dominated the fishery prior to the bleaching event. Impacts occurring at small spatial or temporal scales would be masked by fishermen changing their fishing habits and patterns. The impacts upon fisheries may become more pronounced once the structural frame of bleached reefs is eroded.

### CCF-II: SURPRISE IMPACTS

With nearly 60% of the world's reefs threatened by bleaching, pollution and disease, it is plausible to project a collapse of coral reefs in the next several decades. Just 1°C additional warming of sea surface temperatures could bleach the entire ring of coral reefs.

Costing the loss of Earth's oldest habitat makes little sense. The economic valuation of about US \$800 billion for the world's reefs may vastly underestimate their irreplaceable role. The economic and social value of assuring the survival of coral reefs and the ecosystems associated with them (that is, seagrasses, mangroves, beach and upland communities) is not possible to quantify.

Potential economic impacts following the collapse of coral reef ecosystems are of great concern. Recovery of damages to tourist-related structures (including shoreline hotels, losses of homes, roads and bridges) would require major financial support. Economic resources would be necessary to repair storm-damaged properties (homes, buildings, piers, boats), to meet elevated local health care costs stemming from environmental illnesses, and also to compensate unemployed local workers. The loss of reefs as tourist attractions and the loss of reef protection against storm surge, together with sea level rise, will create socio-economic catastrophes in low-lying islands and coastlines.

Tourism in the Caribbean generates over US \$16 billion annually. The combination of sea level rise, coral reef destruction, more intense storms, more powerful storm surges, and more epidemics of vector-borne diseases (such as dengue fever) collectively pose substantial risks for tourism, travel and allied industries.

Disruption of low-lying coastal areas and island life from the combination of saltwater intrusion into aquifers, the loss of barrier and fringing reefs, and more intense tropical storms could displace many island and low-lying nation populations, resulting in heightened political and economic pressures on other nations. The generation of large numbers of environmental refugees and internally displaced persons may present the greatest short-term costs to international security and stability.

## SPECIFIC RECOMMENDATIONS

The full impacts of global warming may be delayed by reducing the direct anthropogenic threats to coral survival. Direct contact between tourists and coral, boat and anchor damage, release of debris and chemical pollutants around reefs, and unsustainable harvesting activities for recreation and commerce are detrimental to reef resilience. Marine Protected Areas provide the framework for preserving these vital areas.

Implementation of conservation measures must be comprehensive in order to have a substantial and lasting effect. The measures include:

- Treatment of domestic sewage to tertiary breakdown levels before release into far-offshore marine environments.
- Reduced use of fertilizers and pesticides in near-shore coastal communities.
- Implementing fishing quotas, establishing 'no-go' zones and seasons, and designating temporary no-harvesting zones, to allow for replenishment and protection of shellfish and finfish stocks.
- Preserve contiguous areas of the interconnected upland forest and watershed systems, coastal wetlands, mangrove stands and spawning lagoons.
- Adhering to regulations regarding Marine Protected Areas and restricted access zones along coastal areas.
- Banning and monitoring compliance for destructive fishing practices, for example, dynamite and cyanide used for fishing, and removal of reefs for construction.

- Terminating practices that destroy or extract reef frame for ornamental aquarium trade, construction materials, navigational clearance, and for other commercial applications (for example, coral calcium health supplements).
- Develop and expand regulated, sustainable and environmentally friendly ecotourist activities in tropical settings.

Together, these local measures can make restoration and recovery of residual reefs possible. But for reefs, even more so than other ecosystems, their survival is intimately tied to stabilization of the global climate.

## CASE 2. MARINE SHELLFISH

Eileen Hofmann

Figure 2.33 Oysters



Oysters feed by filtering gallons of water each day to extract nutrients and plankton. This filtering activity helps keep bays clear and clean. Image: Lyn Boxtor/Dreamstime

### BACKGROUND

The Eastern oyster (*Crassostrea virginica*) has been a major component of the biology and ecology of Chesapeake Bay for the past 10,000 years (Mann 2000). This species supported a strong commercial fishery for the first part of the twentieth century. During the past four decades, Eastern oyster populations in Chesapeake Bay have been greatly reduced by the effects of two protozoan (one-cell animal) diseases: Dermo, caused by *Perkinsus marinus*, and Multinucleated Spore Unknown (MSX), caused by *Haplosporidium nelsoni*. The addition of overfishing and habitat deterioration has caused a long-term decrease in Eastern oyster populations in Chesapeake Bay. The result is that native oyster populations are now only a small percentage of the populations that existed until the middle of the last century.

Benthic (bottom-dwelling) filter feeders like oysters are an important component of estuarine and coastal food webs. Loss or reduction of these organisms can have a large effect on ecosystem structure and function as well as economic impacts, as many are commercially harvested shellfish. The current condition of Chesapeake Bay oysters illustrates the imports of losing any important, keystone component of the marine food web.

Newell (1988) estimated that the pre-1870 oyster stocks in the Maryland waters of Chesapeake Bay would have been capable of removing 77% of the 1982 daily carbon production in waters less than nine meters deep. Newell further concluded that oysters were once abundant enough to have been the dominant species filtering carbon from the water column in Chesapeake Bay.

It should be noted that the Eastern oyster is only one of many shellfish species that are being impacted by diseases that are thought to be gaining in prevalence and intensity due to a changing climate. For example, Brown Ring Disease, caused by *Vibrio tapetis*, in Manila clams (*Ruditapes philippinarum*) has had a significant impact in Europe.

### DERMO AND MSX

Dermo and MSX are parasitic diseases that affect oysters. They render these bivalves uneatable, but the parasite itself is not known to harm humans.

Dermo is an intracellular parasite (2 to 4  $\mu\text{m}$ ) called *Perkinsus marinus*, that infects the hemocytes of the eastern oyster, *Crassostrea virginica*. Dermo is transmitted from oyster to oyster. Natural infections are most often caused by parasites released from the disintegration of dead oysters. Waterborne stages of the parasite may spread the disease over long distances. Transmission may also occur by vectors such as scavengers feeding on infected dead oysters or by parasitic snails. Alternate molluscan hosts can serve as important reservoirs for Dermo.

Since Dermo is considered a warm water pathogen that proliferates most rapidly at temperatures above 25°C (77°F), ocean warming influences its activity and range climate. In the northeast US, the disease may become endemic as a result of a series of warm winters. However, Dermo can also survive freezing. It is suppressed by low salinities, less than 8 to 10 parts per thousand, but the parasite proliferates rapidly when oysters are transplanted into higher salinity waters (Ford and Tripp 1996).

Dermo disease caused extensive oyster mortalities in the Gulf of Mexico in the late 1940s. Later, it caused chronic and occasionally massive mortalities in the Chesapeake Bay. Since 1990, Dermo has been detected in Delaware Bay, Long Island Sound, Massachusetts, Rhode Island and Maine.

MSX (multi-nucleated spore unknown) is now known to be caused by the parasite *Haplosporidium nelsoni*. MSX caused massive oyster mortalities in Delaware Bay in 1957 and two years later in Chesapeake Bay. The parasite has been found from Florida to Maine, but has not been associated with mortalities in all areas. MSX was found in oysters from Connecticut waters 30 years ago. MSX disease is suppressed by low salinities and low temperatures. As described by the Connecticut Department of Agriculture, there is low oyster mortality during the winter months and the prevalence and intensity of the disease decreases. A second mortality period occurs in late winter and early spring (Ford and Tripp 1996).

## THE ROLE OF CLIMATE

As with human diseases, the sequential occurrence of events, such as a warm winter followed by a warm, dry summer, can result in disease prevalence and intensities greater than normal (Hofmann et al. 2001). The intensification of Dermo disease coincided with a period of sustained drought, diminished freshwater inflow to the Chesapeake Bay, and warmer winters. The drought and warmer temperatures, which cause increased evaporation, combined with the reduced freshwater input, resulted in increased salinity of the Bay waters. The increased salinity allowed the disease-causing parasite to increase in prevalence and intensity. The milder winters allowed the parasite to survive and remain at high levels in the oyster population. Reduction and/or cessation in harvesting pressure have not resulted in significant recovery of the stocks. The mitigation strategies were too late and did not anticipate the increase and spread of Dermo disease that has occurred as the climate has warmed.

## NORTHWARD MOVEMENT

From the late 1940s when Dermo disease was first identified (Mackin et al. 1950) until the 1990s, Dermo disease was found primarily from Chesapeake Bay south along the Atlantic coast of the United States and into the Gulf of Mexico. In 1990 and 1991 the parasite causing this disease was found in locations from Delaware Bay, NJ, to Cape Cod, MA. It is now found in oyster populations in Maine and southern Canada, where it has caused epizootics (epidemics among animals — in this case, shellfish) that have devastated oyster populations and the oyster fishery. Several hypotheses have been suggested for the observed expansion in range of this disease. The one that is most consistent with the available evidence is that this parasite was introduced into various northern locations where it remained at low levels until the recent warming climate allowed it to proliferate (Ford 1996). In particular, above-average winter temperatures during the 1990s along the eastern United States and Canada (Easterling et al. 1997) have allowed the parasite that causes Dermo disease to become established (Ford 1996; Cook et al. 1998). Also, the interannual variation in prevalence and intensity of Dermo disease in oysters along the Gulf of Mexico has been shown to be related to shifts in the ENSO cycle (Kim and Powell 1998), also an indication that climate is a strong contributor. This relationship arises through changes in temperature and salinity that result from the ENSO cycle, which directly affect *Perkinsus marinus* growth and development. The disease is much more intense and prevalent throughout the Gulf of Mexico during La Niña events, which produce warmer and drier conditions and often drought (Kim and Powell 1998).

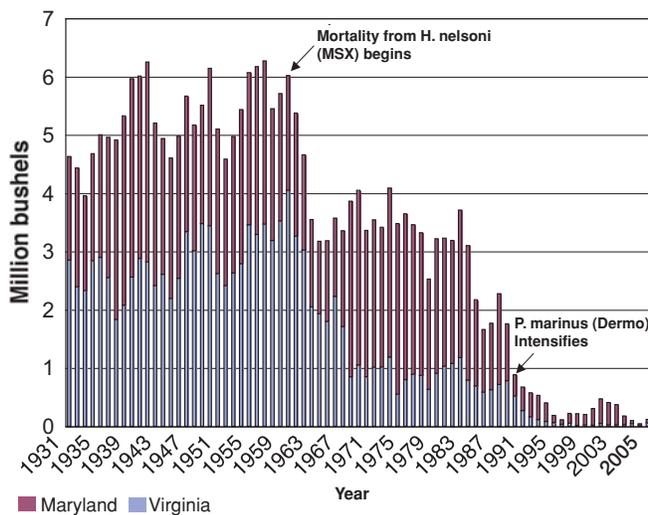
## HEALTH AND ECOLOGICAL IMPACTS

Oysters and other bivalves (clams and mussels), in addition to serving as food for humans and shorebirds, are filter-feeders. Each oyster can pull in many gallons of water a day, filtering out the nutrients and plankton for its own nourishment. In this way, they provide a critical ecological service: controlling the nutrient and algae level in bays and estuaries. Without bivalves, these coastal waters would turn murky, and contaminated, and algal mats would create hypoxic or anoxic conditions. Such waters become less productive for fish, shellfish and sea grasses that support the fish, and shellfish can die off and the few fish left tend to

become contaminated with viruses and bacteria. Surrounding communities can lose their fisheries and livelihoods.

The Chesapeake Bay does not have other benthic filter feeders with population levels that approach historic oyster levels. The result is that the ecosystem structure of Chesapeake Bay has been altered because of the loss of oysters. With changes in nutrient cycling, Chesapeake Bay has reduced water clarity, seagrass beds and associated biological communities, increased prevalence of stinging sea nettles (*Chrysaora quinquecirrha*), and increased regions of hypoxia in bottom waters of the Bay during warmer months. All these impacts have implications for the biological production of the Bay and the economic and recreational use of Bay resources.

Figure 2.35 Chesapeake Bay Market Oyster Landings: 1931-2005



Step-wise drops in Chesapeake Bay oysters have been associated with disease changes, and the population of sulfur-feeders has not recovered.

## ECONOMIC DIMENSIONS

The range of economic impacts include: reduced shellfish harvests, impacts on community livelihoods, fish trade and restaurants, recreational fishing and tourism. The loss to the Delaware Bay oyster fishery as a result of disease is estimated to range from US \$75 to US \$156 million per year. The range in the estimates arises from the lack of a reliable baseline for the calculations and underscores the need for sustained monitoring programs. Considerable resources are being expended to restore oyster population levels in Chesapeake Bay (NRC 2004).

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Continued warming conditions and warmer winters at northern latitudes will favor the spread of Dermo disease to oyster populations in northern bays and estuaries. Warming will also support increased parasite prevalence and intensity, thus enhancing disease transmission. The primary mechanisms by which oysters survive Dermo disease are through reduction in the pathogen body burden when winter temperatures drop, and by the ability of oysters to grow faster than do the parasites. However, warmer winters will result in higher burdens of Dermo parasites, so that oysters emerging from the winter will be less able to outgrow the disease.

The social and economic consequences of the reduction in the oyster harvest in Chesapeake Bay provide a preview of the potential effects that can occur on a larger scale if Dermo and MSX diseases becomes established in northern oyster populations.

### CCF-II: SURPRISE IMPACTS

Transfer of diseases of oysters to other coastal regions in the US and to other nations could have devastating impacts on the productivity in bays and estuaries over a much wider region. The impacts would ripple through the marine food web, affecting shell and fin fisheries beyond oysters, as well as seabirds and marine mammals. Removal of large populations of filterers would lead to much greater nutrient loads (eutrophication), decreased water quality and clarity, and would exacerbate the hypoxic "dead zones" afflicting over 150 coastlines worldwide.

## SPECIFIC RECOMMENDATIONS

The importance of the oyster as an integral component of the biology and ecology of Chesapeake Bay and as a commercially harvestable resource has resulted in efforts to understand the decline in population number and to develop approaches to restore population abundances to previous levels. Considerable effort has been expended in developing oysters that have been genetically modified to include genes that provide resistance to Dermo disease. Some success has been obtained in restoring reefs in limited areas through planting of these oysters. Although the introduced oysters are triploid (not able to reproduce), some small percentage of these animals revert to a diploid form and do produce larvae. The long-term effect of cross-breeding between the

genetically modified animals and native oyster populations is yet to be determined.

Another recent development in the attempts to restore Chesapeake Bay oyster populations is the proposed introduction of a non-native oyster, the Suminoe oyster (*Crassostrea ariakensis*) into Chesapeake Bay with the intent of developing a viable population that can restore ecosystem services (Daily 1997) and enhance the wild fishery. The apparent rapid growth rate of the Suminoe oyster and its resistance to local diseases makes this an attractive species for introduction (NRC 2004).

The scientific basis for making informed decisions about the potential biological and ecological effects of introductions of non-native and/or genetically modified oyster species needs much more thorough study. For example, the potential of altering the genotype of the native oyster species by interbreeding with the genetically modified oysters represents an unknown that could cause unforeseen and abrupt perturbations to the ecosystem.

The concerns associated with introduction of this non-native species include the introduction and/or enhancement of different diseases, the spread of the species to non-target regions, the competition with native oysters and other native species, and the potential for biofouling. The present knowledge of the biology and ecology of the Suminoe oyster is limited. There are now ongoing research programs that are focused on studies of the physiology and ecology of post-settlement and larval Suminoe oysters. However, the introduction of this species into Chesapeake Bay will take place prior to the availability of the ecological data needed to fully evaluate the impact of this species on the Chesapeake Bay ecosystem (NRC 2004).

Specific measures include the following:

- Develop monitoring systems with sufficient data collection frequency to differentiate between natural variability and long-term climate change effects.
- Provide funding, infrastructure and resources for long-term monitoring of habitat quality.
- Undertake studies that can identify long-term climate change processes that may result in environmental changes that facilitate the spread of bivalve diseases.
- Develop management and decision-making structures/policies that include effects of environmental variability and the potential effects of long-term climate change.



## WATER

### THE EFFECTS OF CLIMATE CHANGE ON THE AVAILABILITY AND QUALITY OF DRINKING WATER

Rebecca Lincoln

#### BACKGROUND

Water is essential to life on Earth. Yet clean, safe water supplies are dwindling as demand rises. Population growth, increases in agricultural and industrial demands for water, and increased contamination have already put a strain on water resources. Global climate change threatens to intensify that strain, through decreased availability and quality of drinking water resources worldwide, and through increased demand on these resources due to rising temperatures.

According to the World Health Organization (McMichael et al. 2003), an estimated 1.1 billion people, or one of every six persons, did not have access to adequate supplies of clean water in 2002 and at least 1 billion people must walk three hours or more to obtain their water (Watson et al. 2000). A country is considered to be experiencing "water stress" when annual supplies fall below 1,700 cubic meters per person and "water scarcity" when annual water supplies are below 1,000 cubic meters per person. By these measures, according to The Irrigation Association (a consortium of businesses), 36 countries, with a total of 600 million people, faced either water stress or water scarcity in 2004.

If present consumption patterns continue, the United Nations Environment Programme estimates that two out of every three persons on Earth will live under water-stressed conditions by the year 2025. These dire projections do not take into account a changing climate. Many of the world's arid and semi-arid regions cover developing countries, and water stress in these countries is often compounded by poor infrastructure for collecting, disinfecting and delivering water. A change in climate could have a particularly severe impact on water quality and available quantity in these regions.

In 2001 the IPCC fully recognized that the impacts of future changes in climate are expected to fall disproportionately on the poor (McCarthy et al. 2001).

Changes in water for consumption, cooking, washing, waste disposal, agriculture, hydropower, transport, manufacturing and recreation are likely to grow critical in large parts of the world in the coming decades.

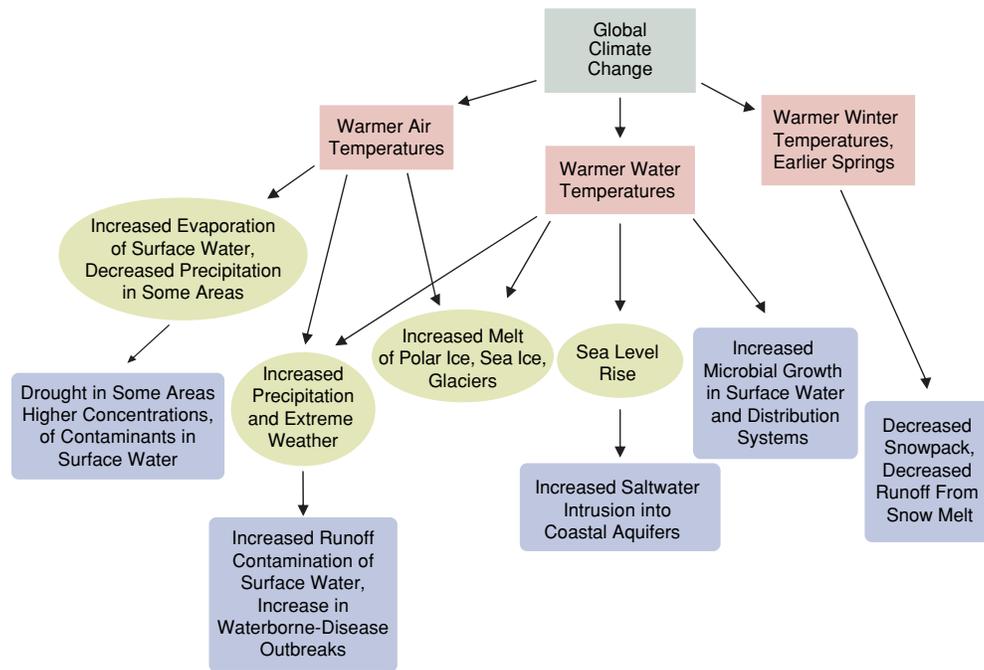
## THE ROLE OF CLIMATE

Warming affects water quality, while precipitation patterns affect groundwater aquifers, surface waters, snowpack accumulation and water quality. Outbreaks of waterborne diseases, large freshwater and marine algal blooms, and increased concentrations of agricultural chemicals and heavy metals in drinking water sources have all been linked to increased temperatures, greater evaporation and heavy rain events (Chorus and Bartram 1999; Levin et al. 2002; Johnson and Murphy 2004), which can increase microbial, nutrient and chemical contamination in waterways and water delivery systems.

Ambient temperatures and precipitation influence the range, survival, growth and spread of pathogenic microbes. Sewage and urban, agricultural, and industrial wastes are the primary sources of contamination, and microbes must enter source water in relatively high concentrations to initiate a waterborne disease outbreak (WBDO). The microbes must be transported to a treatment plant and pass through the treatment process, or enter the water supply through cross-contamination with untreated water. The latter can happen when contaminants enter breaks in distribution pipes or when combined sewer systems overflow (Rose et al. 2001). Poor infrastructure and inadequate centralized drinking water treatment greatly magnify the risk of illness from WBDOs.

Water quantity is also very sensitive to precipitation patterns and temperature. These parameters directly affect the amounts that fall, that which is available in surface waters, that which is absorbed and stored in underground aquifers, that which is stored in polar and mountain snow and ice fields, and the timing and quantities that flow during melting.

Figure 2.35



Pathways by which climate change can alter health and agriculture via changes in precipitation patterns, water/ice/vapor balance, sea level, water quality and snowpack spring runoff. Source: Rebecca Lincoln

## HEALTH AND ECOLOGICAL IMPACTS

Access to safe, adequate drinking water is considered a primary driver of public health. The World Health Organization estimates that 80% of worldwide disease is attributable to unsafe water or insufficient sanitation (WHO, in Cooper 1997). Waterborne diarrheal diseases are the primary causes of water-related health problems.

Warmer temperatures can lead to increased microbial and algal growth in water sources. Studies have linked yearly outbreaks of gastroenteritis among children in Harare, Zimbabwe, to seasonal freshwater algal blooms with cyanobacteria (blue-green algae) in the reservoir that supplies their neighborhoods with water (Chorus and Bartram 1999; Zilberg 1966). In Bahia, Brazil, a 1988 outbreak of gastroenteritis that killed 88 people living near the Itaparica Dam was linked to a large bloom of cyanobacteria in the dammed lake (Chorus and Bartram 1999; Teixeira et al. 1993).

As increased temperatures and decreased precipitation lead to a decrease in water volume of surface sources, the concentration of contaminants such as heavy metals and sediments will increase (McCarthy et al. 2001; Levin et al. 2002). For example, Lake Powell, in Utah, covers 160,000 acres when full, but has lost 60% of its volume in recent droughts. As the water level drops, agricultural chemicals that have been collecting on the lake's bottom since its creation may begin to mix with water traveling through the dam at the base of the lake. This could result in contamination of the Grand Canyon, which lies about 75 km downstream (Johnson and Murphy 2004).

Precipitation plays a large role in waterborne-disease outbreaks. Heavy rainfall can wash microbes into source waters in large quantities, in addition to causing combined sewers to overflow. Microbes are also transported much more easily through saturated soil than through dry soils (Rose et al. 2001). Many studies demonstrate a correlation between heavy rainfall and outbreaks of waterborne diseases, including cryptosporidiosis, giardiasis and cyclosporidiosis (Checkley et al. 2000; Speelman et al. 2000; Curriero et al. 2001; Rose et al. 2000; Casman et al. 2001). Between 1948 and 1994, 68% of all waterborne-disease outbreaks in the US occurred after rainfall events that ranked in the top 20% of all precipitation events by the amount of water they deposited (Curriero

2001). These outbreaks showed a distinct seasonality, becoming more frequent in summer months, and cyclosporidiosis incidence in Peru was found to peak during the summer as well, suggesting that temperature also plays a role in WBDO patterns (Rose et al. 2001).

During the El Niño event of 1997-1998, with mean temperatures 3.4°C higher than the average of the previous five summers, reported cases of both cholera (Speelman et al. 2000) and childhood diarrhea (Checkley et al. 2000) in Lima, Peru, increased significantly. The growth of *Vibrio cholerae* (the pathogen that causes cholera) and other pathogens responsible for diarrheal diseases accelerates in warm conditions. The growth of microbial slime in biofilms in water distribution systems is also sensitive to temperature, and it is likely that microbes in biofilms acquire resistance to disinfectants at high rates (Ford 2002).

Due to underreporting of diarrheal illnesses, the prevalence of waterborne diseases may be much higher than is currently believed (Rose et al. 2001). For the general population, these waterborne diseases are not usually serious, but they can be fatal if water, sugars, and salts are not replaced. For example, the mortality rate for untreated cholera is approximately 50%, while the mortality rate for properly treated cholera is 1%.

Vulnerable populations, such as immunocompromised people (those with weakened immune systems) — including infants, the elderly and pregnant women — are more susceptible to waterborne diseases. Among AIDS patients in Brazil, cryptosporidiosis was the most common cause of diarrhea (Wuhib et al. 1994), and 85% of the deaths following a cryptosporidiosis outbreak in Milwaukee, WI, in 1993 occurred in those with HIV/AIDS (Hoxie et al. 1997).

## ECONOMIC DIMENSIONS

Based on the midrange 1996 IPCC projections for doubling of CO<sub>2</sub> (2.5°C, or 4.5°F), Hurd et al. (1999) project US losses from such parameters as water-quality changes, hydroelectric power losses, and altered agriculture and personal consumption to be US \$9.4 billion. With a 5°C rise in global temperatures, without changes in precipitation, the estimates rise to US \$31 billion for water-quality impacts out of a total of US \$43 billion damage. These estimates, it should be noted, do not take into account variance and the increasing frequency of heavy and very heavy rain events accompanying warming (Groisman et al. 2004).

While seawater desalination is currently not cost-effective, it has gradually become cheaper, and as the demand for safe water increases, it is likely that technological advances will bring the cost down to a reasonable level (Levin et al. 2002). Meanwhile, the energy demands of this process are enormous, and the fossil fuels that are used to desalinate water will contribute greenhouse gases to the environment and compound the problem. Solar desalination may be a safe and less expensive method in the future.

## THE FUTURE

### CCF-I: ESCALATING IMPACTS

Changes in temperature and weather patterns due to global climate change will have serious consequences for drinking water supplies. Patterns of warmer air and surface water temperatures, increased frequency of extreme weather events, rising sea levels, increased evaporation of surface water, decreased snowpack, and earlier snowmelt all threaten to compromise the quantity and quality of drinking water in many parts of the world. These trends could result in regional drought conditions and a decrease in seasonal runoff, intrusion of saltwater into coastal aquifers, diminished aquifer recharge, increased microbial growth and harmful algal blooms, increased contamination of surface water, and increased incidence of waterborne diseases. The chart on page 87 describes the multiple effects of global climate changes on water resources.

An increase in ambient air temperatures due to global warming, as well as an increase in surface water temperatures, will increase the amount of water residing in the atmosphere as vapor, leading to a net loss in precipitation and in the amount of surface water worldwide. Increased evaporation could also lead to water stress and drought conditions for arid regions that don't experience an increase in precipitation (Levin et al. 2002), and current climate models being used by the IPCC predict decreased precipitation in many equatorial areas, leading to a decrease in surface water source volume and in groundwater recharge. The intensity and duration of droughts in some regions of Asia and Africa have already been observed to have had increased over the last few decades (Albritton et al. 2001).

Warming will also lead to a rise in sea level, due to glacial melt and thermal expansion. In coastal zones that rely on shallow surface aquifers for drinking water, this rise in sea level leads to saltwater intrusion into freshwater aquifers, contaminating drinking water supplies.

Water availability in high-latitude and mountainous regions is often characterized by heavy runoff and peak stream flows in the spring due to snowmelt, followed by a drier summer and fall. Winter precipitation falls mostly as snow, and is stored until spring in snow pack instead of immediately running off or filtering into the ground. Warmer winters and earlier springs associated with climate change will result in more winter precipitation falling as rain, decreasing the accumulation of snow pack. It is likely that warming will also alter the timing of melting and peak runoff, resulting in an earlier and more rapid spring runoff (Levin et al. 2002; Frederick and Gleick 1999). These predictions are borne out by observed changes in stream flow patterns around the world; earlier peak runoff in the spring and increases in fall and winter runoff are some of the most frequent changes noted (Frederick and Gleick 1999). Agriculture in these regions will be adversely affected, as spring snowmelt often provides water for irrigation at a crucial point in the growing season.

Because warmer temperatures and more extreme rainfall patterns increase the frequency of WBDOs, it is likely that waterborne disease will be an even more serious health problem in the 21st century than it is today (Levin et al. 2002).

Continued warming and more extreme weather patterns are likely to have a marked and adverse effect on the distribution and quality of drinking water worldwide. Water shortages and water-related illnesses could become more widespread and more frequent, putting enormous pressure on watersheds, water delivery systems and health care systems. Agricultural impacts could be severe, especially as irrigation needs rise due to warmer global temperatures, and hydroelectric power could be severely compromised in many nations. Water shortages could lead to intense competition and more violent conflicts, as demand rises, aquifers and surface water bodies become depleted, and changes in the hydrologic cycle make water supplies more varied and unpredictable. While climate change impacts on water resources are likely to be severe worldwide, they will be far worse for developing countries with inadequate infrastructure, resources and adaptive capacities.

## CCF-II: SURPRISE IMPACTS

Increasingly variable and unpredictable changes in climate could result in widespread water shortages, generating mass migrations of displaced persons. Competition over scarce resources and conflict over water resources in particular is common historically (Gleick 2004), and drastic changes in climate accompanied by a decrease in water availability are likely to trigger tension and conflicts between groups that compete for water (McCarthy et al. 2000; Yoffe et al. 2003).

Non-linear climate change will also pose a significant challenge for water resource management and planning, since management practices have just began to take linear, small-scale climate changes into account. Modeling water flow regimes under a variety of climate change scenarios is one way to address this problem. Models of US runoff patterns indicate that the timing of the melt and runoff season will shift toward earlier in the spring with an increase in peak runoff, and that winter runoff will increase while spring and summer runoff decrease (Frederick and Gleick 1999). A model of hydrologic flow patterns in central Sweden consistently showed decreased snow accumulation, significant increases in winter runoff, and decreases in spring and summer runoff under a variety of scenarios of increased temperature and precipitation (Xu 2000; Watson et al., 2000). Under the most extreme climate scenarios, mean annual runoff was predicted to change by up to 52%, and annual total evapotranspiration was predicted to change by up to 23% (Xu 2000). These trends could have serious and complex implications for water management practices, and highlight the need for current planning and management of water resources that take into account a changing climate.

## SPECIFIC RECOMMENDATIONS

Structural problems in water treatment and distribution systems, such as aging, breakage and the use of combined sewer systems, need to be fixed. Monitoring for early warning signs of waterborne disease outbreaks, such as increased contaminant loads in source waters, heavy rainfall events, or other extreme weather conditions, could be useful in preparing for and preventing outbreaks. Better protection of source water bodies and their surrounding watersheds will help to prevent problems of contamination and disease in the treatment and distribution phases.

Isolated short-term measures to address these problems are not a sustainable strategy for ensuring safe, abundant water supplies. The likelihood of a drastically changing climate must be taken into account in making planning, management and infrastructure decisions in the future (Rose et al. 2000). A combination of infrastructure improvement, sustainable planning, watershed management, and environmental protection can have profound effects on the health and well-being of millions of people.

Figure 2.36 Village Water Spout



*Household water is rare in many nations. Absence of running water is highly correlated with gastrointestinal illness.  
Image: Pierre Viot/WHO*

**PART III:**

*Financial Implications, Scenarios and Solutions*

*“Climate change is one of the world’s top long-term risk scenarios.”*

*- John Coomber, Former CEO, Swiss Re (Swiss Re 2004a)*

*“A severe natural catastrophe or series of catastrophes could generate major insurance market disruptions.”*

*-US General Accountability Office (GAO 2005)*

## FINANCIAL IMPLICATIONS

With over 3 trillion dollars in annual revenues<sup>1</sup>; insurance is the world’s largest industry.<sup>2</sup> It represents 8% of global GDP, and would be the third largest country if revenues were compared with national GDPs.

Insurance provides a mechanism for spreading risk across time, over large geographical areas, and among industries. The core business of insurance traditionally involves technical strategies for loss reduction as well as financial strategies for risk management and risk spreading. The growing repository of insurance loss data augments the geophysical observing systems with trends in financial losses.

The core business of insurance, as well as the sector’s activities in financial services and asset management, are vulnerable to climate change (see figure 3.1). As such, insurers are impacted by and stand to be prime movers in responding to climate change (Vellinga et al. 2001; Mills 2004). “Insurance is on the front line of climate change ... and it is insurers who must be equipped to analyze the new risks that flow from climate change, and to help customers to manage these risks” (ABI 2004). Nonetheless, it must also be kept in mind that insurance is one element of a much broader patchwork for spreading risks (see figure 3.2); and insurers may not have as long a time horizon as do reinsurers.

Owing to the types of hazards that tend to be insured, the largest proportion of total catastrophe losses sustained by insurers is weather-related.

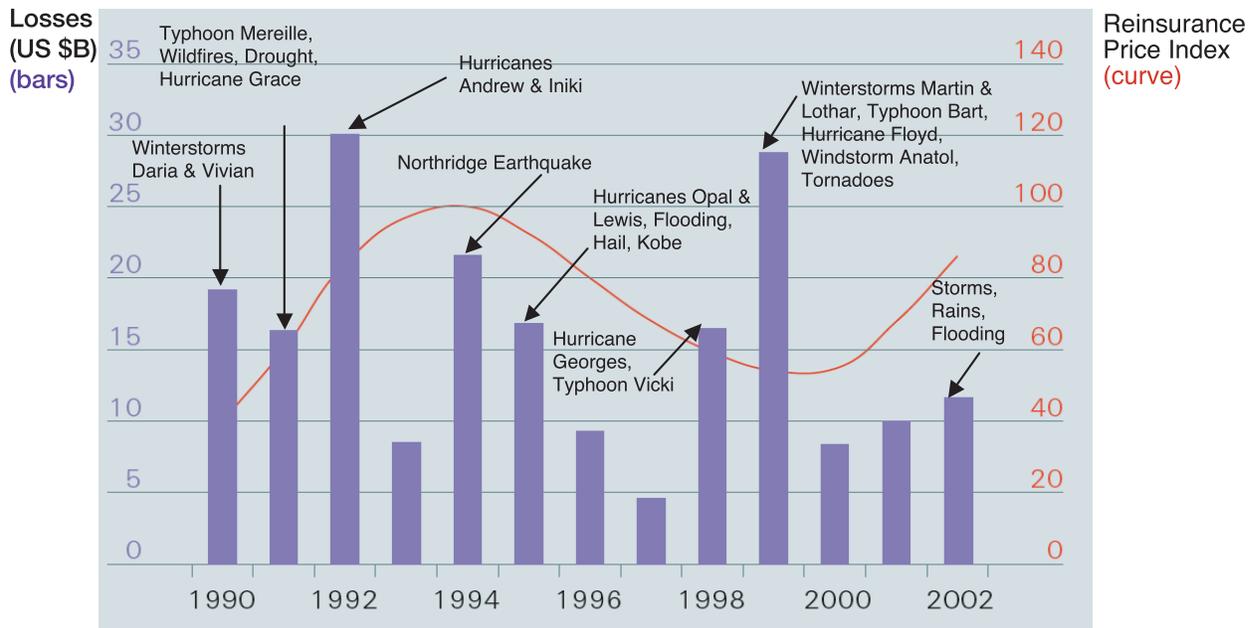
The availability and affordability of insurance is essential to economic development, financial cohesion in society and security and peace of mind in a world where hazards abound and are increasingly unpredictable. Unanticipated changes in the nature, scale, or location of hazards — human-induced or natural — are among the most important threats to the insurance system. This has been seen repeatedly in the past in the aftermath of previously unimagined earthquakes, windstorms and terrorist events. Observers from Florida note that “[Hurricane] Andrew exposed old methods, such as trending historical hurricane loss totals, as ill-suited for managing and pricing hurricane exposure” (Musulin and Rollins 2005). Despite this record, there is, oddly, continued skepticism when the specter of new and unprecedented types and patterns of events emerge. An eye-opening industry report from the mid 1980s (AIRAC 1986) highlighted the importance of considering multiple catastrophes in a single year, while observers nearly 20 years later lament the catastrophic results of the industry’s failure to adopt this perspective in advance of the four-hurricane season in 2004 (Musulin and Rollins 2005; Virkud 2005, Harrington et al. 2005).

Most discussions and climate impact scenarios are cast from the vantage point of the natural sciences, with little if any examination of the economic implications. Moreover, the technical literature often takes a “stovepipe” approach, examining specific types of events in isolation from the real-world mosaic of often interrelated vulnerabilities, events and impacts. For example, analyzing the effects of drought on agriculture may be done in isolation, effectively suppressing

<sup>1</sup> Detailed country-by-country statistics (in US dollars and local currencies) are published in Swiss Re’s annual sigma “World Insurance” reports (for example, Swiss Re 2004b). Data presented in this report represent Western-style insurance and do not include the premium equivalents that are collected from alternative systems, such as Takaful methods used in the Muslim world or so-called “self-insurance,” which is often formalized and represents considerable capacity.

<sup>2</sup> Defined in terms of revenues for specific commodities or services, as opposed to more all-encompassing meta-industries such as “retail” or “technology.” The world oil market, for example, is US \$970 billion/year at current production levels of 76Mbpd and US \$35/bbl price [Surpassing US \$60 in summer 2005]; world electricity market in 2001 was US \$1 trillion at 14.8 trillion kWh generation assuming US \$0.07/kWh unit price; tourism receipts were US \$445 billion (2002); agriculture US \$1.2 trillion (2002); world military expenditures were US \$770 billion (2002). Source: 2005 Statistical Abstract of the United States.

Figure 3.1 Reinsurance Prices Are Highly Sensitive to Trends in Natural Disasters



Source: Adapted from Swiss Re (2003)

the linked impacts on human nutrition, financial markets and other hazards — like wildfires and the spread of West Nile virus — that may accompany drought. The approach here is to examine each issue in a more integrated fashion, focusing on the broad perspective of the business world, with emphasis on the insurance sector that must absorb the impacts that fall on multiple sectors.

Forward-thinking individuals from within the insurance community have called for such an integration of natural science and economic perspectives (Nutter 1996). But insurers' catastrophe ("CAT") models are based on the past rather than future climate and weather projections. In response to the unanticipated life insurance catastrophe following the attacks of 9/11, models are now being employed to project life insurance exposures (Best's Review 2004; Chordas 2003).

The triggering events considered here arise from gradual climate change. Including catastrophic abrupt change would yield significantly more adverse outcomes. And while the events depicted here are not always physically severe, their consequences are severe primarily because they are unanticipated and not proactively prepared for. As the historic record demonstrates, insurance prices are strongly influenced by trends in natural disasters, which, in turn, have implications for demand (figure 3.1). Risks can be

divided into those driven by changes in weather patterns (technical) and those determined by changes related in market-related factors.

### TECHNICAL RISKS:

- Changes in return periods:
  - Increased frequency of events puts new strains on reserves for paying losses.
- Changes in the variability of occurrences:
  - Increased actuarial uncertainty makes it harder to price insurance.
- Changes in the spatial distribution, strength and sequence of events:
  - Had Hurricane Andrew struck 10 miles to the north, losses would have been three- to four-times greater (Hays 2005).
  - When multiple storms occur in one region, the impacts of the early events increase vulnerability to the later ones.
  - Droughts increase vulnerability to flooding from subsequent rains.
- Increased correlation of losses (for example, floods and disease; droughts and heat waves):
  - This is a material concern for insurers, when seemingly uncorrelated events are actually linked or otherwise coincident.

- Increased geographical simultaneity of events (for example, a broad die-off of coral may be followed by an uptick in tidal-surge damages in multiple regions/coastlines):
  - Insurers spread risks (geographically) to reduce aggregate losses.
- Such temporal and geographic “clustering” of impacts has led to the concept of “sideways exposure” in the insurance lexicon.
- Increased difficulty in anticipating “hot spots” (geographic and demographic) for a particular hazard.<sup>3</sup>
- A trend toward hybrid events involving multiple sources of insurance losses is of particular concern (Francis and Hengeveld 1998; White and Etkin 1997):
  - This is exemplified in the case of ENSO (El Niño/Southern Oscillation) events projected to change nature under climate change — which can involve various kinds of losses from rain, ice storms, floods, mudslides and wildfire.
  - Sea level rise is multi-faceted risk, with impacts on flood, property, health and crop insurance (via soil erosion and seawater intrusion into the fresh groundwater called “lenses” underlying tropical isles).
- Novel events, such as the 1999 Lothar windstorm so damaging to France’s forests and the first-ever recorded hurricane in the Southern Atlantic affecting Brazil in 2004:
  - Catastrophe models to date inadequately include many emerging non-linear trends, as well as the multiple “small” serial events associated with a changing climate (Hays 2005).
- Regulatory measures instituted to cope with climate change, which will include measures and practices outside the insurance industry:
  - Emissions-trading regulations and liabilities, or building codes and factors inside the industry — such as changing expectations of insurance regulators. In the wake of the four deductibles charged to some Florida homeowners in the fall of 2004, regulators there mandated reimbursement to 36,000 homeowners, forbade insurers from canceling or non-renewing victims and required “single-season” deductibles for windstorm hazards (Brady 2005).
- “Reputational” risk falling on insurers (and their business partners) who do not, in the eyes of consumers, do enough to prevent losses arising from climate change. A recent survey of companies in the UK found that loss of reputation was the greatest risk they face (Coccia 2005).
- Parallel stresses unrelated to weather or climate, but compounding with climate change impacts to amplify the net adverse impact on insurers:
  - These include drawdowns of reserves due to non-weather-related events, such as earthquakes or terrorist attacks, erosion of customer confidence due to financial unaccountability and scandals, and increased competition from self-insurance and other mechanisms that draw premium dollars out of the insurance sector.

As of today, fewer than one in a hundred insurance companies, and few of their trade associations and regulators, have adequately analyzed the prospective business implications of climate change, heightening the likelihood of adverse outcomes. This is especially so for US insurers, whose European counterparts have studied the issue for three decades (Mills et al 2001). Ultimately, outcomes will depend on the nature of the hazards, broader economic development, regulatory responses, and consumer reactions to changes in public and private risk management systems.

## MARKET-BASED RISKS

- The inadequate projection of changing customer needs arising from climate change:
  - This includes property insurance to cover climate adaptation technologies and new liabilities faced by non-compliant and polluting industries.
  - The consequences can include flight from insurance into other risk-management products and practices.
- The changing patterns of claims. For example, a rise in roadway accidents due to increasingly icy, wet and foggy conditions and associated difficulty in adjusting pricing and reserve practices to maintain profitability.

<sup>3</sup> For example, in 2005 the city of Seattle, WA, issued its first-ever heat warning as the city was added to the US National Weather Service’s excessive heat program, a reflection of the determination that there was an increased possibility of morbidity or mortality from extreme heat events (Associated Press 2005).

## RISK SPREADING IN DEVELOPED AND DEVELOPING NATIONS

The economic costs of recovering from and adapting to weather-related risks are spread among governments (domestically and via international aid), insurers, business, non-profit entities and individuals.

The insurance sector is playing an increasing role (surpassing international aid) and is the only segment with a growing tendency to pay for consistently rising losses (Mills 2004). There is an intrinsic logic for fostering a greater role for insurance in climate risk management, as loss prevention and recovery are historically integral to their business.

Figure 3.2 Costs of Natural Catastrophes Are Spread Among Many Parties



Source: Mills et al. 2001

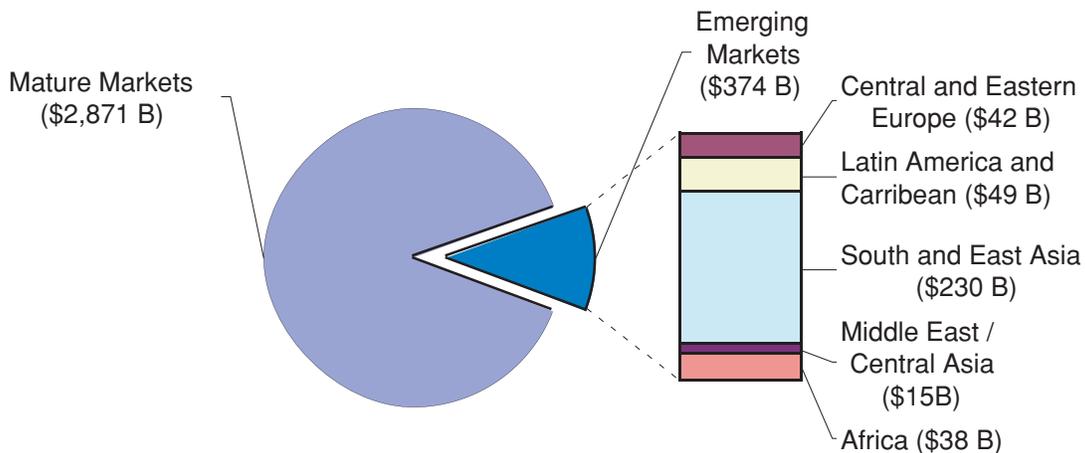
Extreme weather events are a particularly difficult class of risks for insurers to manage, as the industry must maintain the capacity to absorb an uncertain level of losses from year to year. Overall exposures are most acute in the developing world, where vulnerability is high and preparedness low. India and China alone experienced 25% of global economic losses from natural disasters between 1994 and 2003 (Swiss Re 2004b). Total premiums in the emerging markets represented approximately US \$372 billion/year in 2004 or 11.5% of that market, with growth rates often dramatically higher than those in the industrial world (twice as high, on average, over the 1980-2000 time

The potential for new patterns of events stands to raise demand for insurance while increasing uncertainty, challenging the industry's ability and willingness to assume or reasonably price these new risks.

Sustainable development is a guideline that can contribute to managing and maintaining the insurability of these risks and thereby reducing the need for individuals and domestic governments to absorb the costs.

By pooling financial reserves to pay for weather-related damages to property, morbidity and mortality, the global insurance market provides considerable adaptive capacity. Moreover, the economic consequences

Figure 3.3 12% of the US \$3.2 Trillion/Year Global Insurance Market Is in Developing Countries and Economies in Transition: 2004



Emerging markets in underdeveloped nations are a growing part of the global insurance markets. (Micro-financing and micro-insurance are playing roles in development in some nations.)  
Source: Swiss Re 2005b

period), and often exceed national GDP growth rates.<sup>4</sup> (See figure 3.3) At current growth rates, emerging markets will represent half of world insurance premiums by the middle of this century.

Approximately 40% of current-day premiums globally are non-life (property-casualty insurance), with the balance life-health. The insured share of total losses from natural disasters has risen from a negligible level in the 1950s to approximately 35% of the total in 2004 (and up to 50% in some years). Insurance market conditions vary regionally.

of extreme weather events are becoming increasingly globalized, largely due to the multi-national structure of the insurance and reinsurance markets, which pools and integrates the costs of risk across many countries and regions. Foreign insurers' premium growth in emerging markets averaged more than 20% per year through the 1990s. In the late 1990s, the US alone was collecting approximately US \$40 billion in premiums for policies placed in other countries.

<sup>4</sup> The US \$5-10 billion in claims resulting from the 2004 Indian Ocean Tsunami provided a reminder of the degree to which insurance has grown in the developing world.

## THE LIMITS OF INSURABILITY

Not all risks are commercially insurable. A variety of definitions of insurability are found in the literature that differ in detail but share the common theme of accepting or rejecting risks based on the nature of each risk and the adequacy of information available about it (Mills et al. 2001; Crichton 2002; Pearce 2002). The perceived insurability of natural disasters and extreme weather events may be affected by increases in the frequency or unpredictability of these events. If the availability of insurance is consequently reduced, development may be constrained in the emerging markets.

In essence, private insurers set a series of conditions that must be met before they will assume a given risk or enter a given market. These conditions — sometimes referred to as “Standards of Insurability” — are intended to assure the insurers’ financial survival in case of catastrophic losses (see Table, Appendix A). This process involves technical and subjective judgments, and history shows that insurers will relax the standards when profits are high (Swiss Re 2002a).

When private insurers decline to cover a risk, the cost shifts to others. As a case in point, the risk of residential flood damage in the US is deemed largely uninsurable, which has given rise to a National Flood Insurance Program, which has more than 4.2 million policies in force, representing nearly US \$560 billion worth of coverage (Bowers 2001).

## BUSINESS SCENARIOS

### POTENTIAL CONSEQUENCES OF CLIMATE CHANGE FOR THE INSURANCE BUSINESS AND ITS CLIENTS

The following pair of business scenarios — based on current socioeconomic trends and insurance market dynamics — represent business impacts arising from the technical outcomes described in the two CCF scenarios.<sup>5</sup> Both scenarios reflect a “business-as-usual” stance on the part of industry, that is, minimal and gradual interventions to alter the world’s energy diet. In the scenarios for CCF-I, triggering events arise from the consequences of gradual anthropogenic climate change, while those in CCF-II correspond to non-linear impacts. The results are neither worst- nor best-case renditions of what the future could bring.

The scenarios are neither predictions nor doomsday scenarios. Rather, they offer a set of plausible developments in the insurance business environment due to climate change and corresponding developments in insured hazards, industry responses, and, ultimately, impacts on the financial performance and structure of the industry. This approach to building the scenario is similar to that employed in an exercise commissioned by the US Department of Defense to explore the implications of climate instability for conflicts over resources and international security (Schwartz and Randall 2003). The implications for specific segments of the industry are examined and the study concludes with an integrated scenario.

### CCF-I: ESCALATING IMPACTS

In this scenario, weather-related property losses and business interruptions continue to rise at rates observed through the latter 20th century. The insured share increases from a current-day baseline of approximate 25-30%, and underwriting becomes more problematic. Corporations face more environmentally related litigation (and associated insurance payouts), both as emitters of greenhouse gases and from non-compliance with new regulations (Allen and Lord 2004).

A new class of losses involving human health and mortality emerges within the life/health branch of the insurance industry. These are driven by thermal extremes, reduced water quality and availability, elevated rates of vector-borne disease, air pollution, food poisoning, and injuries/mortalities from disasters and associated mental health problems (Epstein 1999; Munich Re 2005). Other health consequences become manifest in natural systems that directly or indirectly impact humans, including coral reef bleaching, agricultural diseases or other events that hamper food production; animal and livestock diseases; and forest pests. Mobilization of dust, smoke, and CO<sub>2</sub>-linked aeroallergens (pollen and mold) exacerbate already high rates of asthma and other forms of respiratory disease.

The combined effect of increased losses, pressure on reserves, post-disaster construction-cost inflation and rising costs of risk capital result in a gradual increase in the number of years in which the industry is not profitable. A compounding impact arises from the continued destructive industry practices of underpricing risk and routinely allowing the core business to operate at a loss, relying instead on profits from investments

<sup>5</sup> This is an elaborated version of a scenario developed and published earlier in the course of the CCF project by Mills (2005).

Table 3.1 Climate Change Threats and Opportunities for the Insurance Industry

<b>Financial Sector Activity</b>	<b>Threat</b>	<b>Opportunity</b>
<b>General Financial Services</b>	<ul style="list-style-type: none"> <li>• New and existing markets become unviable as climate change increases regional exposure</li> <li>• Macroeconomic downturn due to actual impacts</li> <li>• Compounding of climate change risk across entire portfolio of converging activities (asset management, insurance, reinsurance)</li> <li>• Unforeseen changes in government policy</li> </ul>	<ul style="list-style-type: none"> <li>• New markets/products related to mitigation projects/processes</li> <li>• New markets/products related to adaptation projects/processes</li> <li>• Public/private partnerships for commercially unviable markets</li> <li>• Technology insurance and/or contingent capital solutions to guard against non-performance of clean energy technologies due to engineering failure</li> </ul>
<b>Property/Casualty Insurance</b>	<ul style="list-style-type: none"> <li>• Physical damage to insured property from extreme/more frequent weather events, compounded by unmanaged development, resulting in volatile results and liquidity and credit rating problems</li> <li>• Increased risk in other lines of business (e.g., construction, agriculture, transport)</li> <li>• Increases in population and infrastructure densities multiply the size of maximum potential losses from extreme weather events</li> </ul>	<ul style="list-style-type: none"> <li>• Increases in demand for risk transfer and other services as weather risks increase</li> <li>• Insurance of mitigation projects</li> <li>• Innovative risk transfer solutions for high-risk sectors</li> </ul>
<b>Life/Health Insurance</b>	<ul style="list-style-type: none"> <li>• Increased risk to human health (thermal stress, vector-borne disease, natural disasters)</li> </ul>	<ul style="list-style-type: none"> <li>• Increase in demand for products as human health risk rises</li> </ul>
<b>Other</b>	<ul style="list-style-type: none"> <li>• Business interruption risks becoming unpredictable and more financially relevant</li> <li>• Disruptions to construction/transportation sectors</li> <li>• Increased losses in agro-insurance</li> <li>• Political/regulatory risks surrounding mitigation</li> </ul>	<ul style="list-style-type: none"> <li>• Collaboration with others in pooling capital</li> <li>• Microinsurance</li> <li>• Weather derivatives, CAT bonds, etc.</li> </ul>
<b>Asset Management</b>	<ul style="list-style-type: none"> <li>• Hidden GHG liabilities impair market values of securities</li> <li>• Real estate impaired by weather events and increased energy costs</li> <li>• Potential absence of property insurance</li> </ul>	<ul style="list-style-type: none"> <li>• Investment in climate leaders and best-in-sector securities</li> <li>• Innovative climate-related theme funds</li> <li>• Consulting/advisory services</li> <li>• Hedge funds investing in GHG credits</li> </ul>

Source: Adapted from UNEP and Innovest (2002), Mills 2004

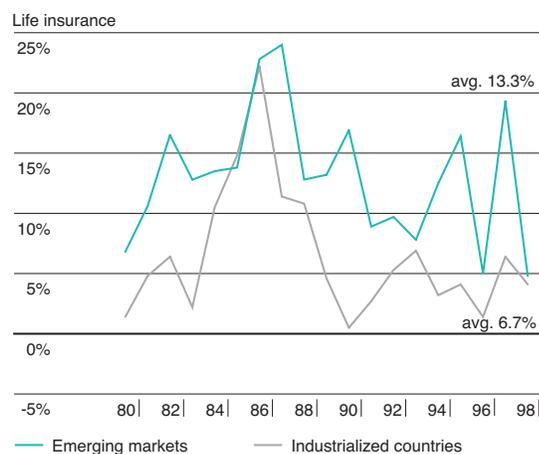
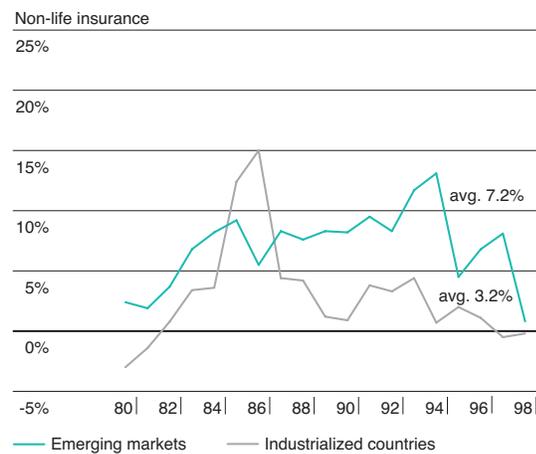
(also known as “cash-flow underwriting”). As occurred after the European windstorms of 1999 (ABI 2004), insurers encounter liquidity problems when paying losses, forcing the sale of large blocks of securities, which, in turn, creates undesirable “knock-on” impacts in the broader financial markets. Outcomes are particularly bad in years when large catastrophe losses coincide with financial market downturns.

Most significantly impacted are insurance operations in the developing world and economies in transition (the primary growth markets for insurance — see figure 3.4), already generating nearly US \$400 billion/year in premiums. This arises from a combination of inferior

disaster preparedness and recovery capacity, more vulnerable infrastructure due to the lack or non-enforcement of building codes, high dependency on coastal and agricultural economic activities, and a shortage of funds to invest in disaster-resilient adaptation projects (Mills 2004). Insurers from industrialized countries increasingly share these losses via their growing expansion into these emerging markets.

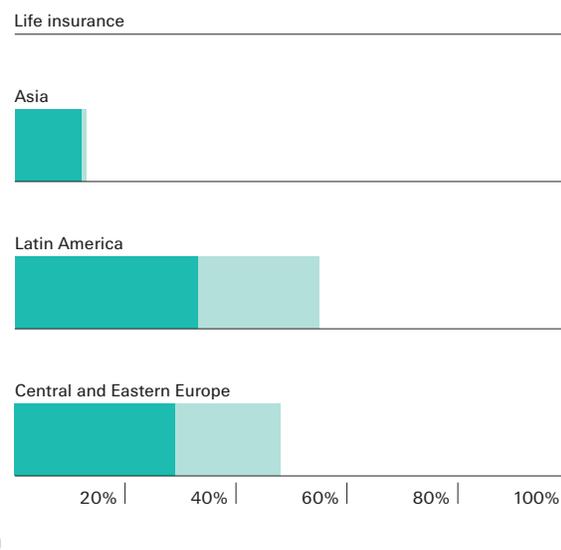
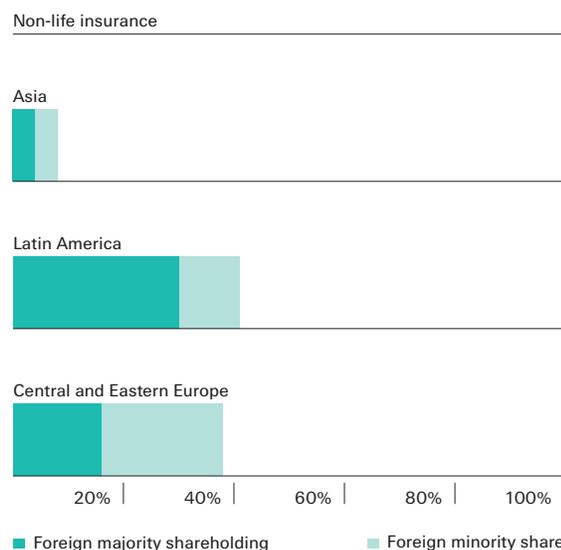
In the face of the aforementioned trends, insurers use traditional methods to reduce their exposures: increased premiums and deductibles, lowered limits, non-renewals, and new exclusions. While consumer

Figure 3.4



Insurance in emerging and industrialized markets.  
Source: Swiss Re 2000, sigma 4/2000

Figure 3.5



Foreign participation in ownership is important in the insurance market  
Source: Swiss Re 2000, sigma 4/2000

demand for insurance increases at first, it evolves into reduced willingness to pay and some shift from the use of insurance to alternatives such as weather derivatives.

As warned by the US Government Accountability Office (GAO 2005), private insurers encounter increasing difficulty in handling extreme weather events. As commercial insurability declines, demands emerge to expand existing government-provided insurance for flood and crop loss, and to assume new risks (for example, for wildfires and windstorms). Cash-strapped governments, however, find that claims interfere with balancing their budgets (Changnon 2003) and, in turn, limit their coverage, with the result that more ultimate losses are shifted back to the individuals and businesses impacted by climate change. Compounding the problem, international aid for natural disasters continues its current decline as a percentage of donor country GDP (Mills 2004).

Climate change accelerates several forms of unrelated adverse structural change already underway in the insurance industry.<sup>6</sup> This manifests as a rise in competition among insurers, significant consolidation due to the reduced viability of small firms, increased risk exposure via globalization and a growing proportion of competing self-insurance and alternative risk transfer mechanisms.

## CCF-II: SURPRISE IMPACTS

A shift from gradual to non-linear impacts of climate change serves to intensify the adverse effects of CCF-I. Disruptions are greater and the economic cost of natural catastrophes rises at an increasing rate, with elevated stress on insurers and reinsurers. This scenario is also fundamentally different for insurers insofar as CCF-I entails relatively predictable changes that can (to a degree) be adjusted to, whereas CCF-II involves a substantial increase in impacts and uncertainty, significant challenges to the actuarial processes that underpin the insurance business.

Life and health impacts are particularly amplified in comparison to the outcomes in CCF-I. Extreme heat catastrophes become more common. Events on a par with that seen in Europe in the summer of 2003 come to the US with the result that offensive air masses of

unprecedented length range from almost 200% to over 400% above average. Intensities also exceed the hottest summers over the past 60 years by a significant margin. All-time records for maximum and high minimum temperature are broken in large numbers of cities, with corresponding death rates five times that previously seen in typical summers. Aside from mortalities, hospitalizations tax hospital resources in emergency room(s) already hit hard by constrained budgets.

Also due, in part, to temperature increases, the current trend towards increasingly damaging wildfires continues. Both a cause and impact of climate change, more fires set intentionally to clear forests and create grazing land in the developing world grow out of control (due to climate-change droughts and high winds). Such associated events caused an estimated US \$9.3 billion in economic damages in 1997 (CNN 2005). Another bad year in 2005 forced the closures of Kuala Lumpur's largest harbor and most other businesses and manufacturing plants, as well as disruption to tourism. A continuation of the trend results in a combination of insured losses, with causes ranging from an upturn in respiratory disease to widespread business interruptions. Included in the impacts are well-insured offshore industries, based in industrialized countries.

The combination of more aeroallergens, rising temperatures, greater humidity, more wildfire smoke, and more dust and particulates considerably exacerbates upper respiratory disease (rhinitis, conjunctivitis, sinusitis), lower respiratory disease and cardiovascular disease. Cases of asthma increase sharply. A 30% increase in cases would occur, raising the total to about 400 million new cases per year by 2025. The baseline cost was US \$13 billion/year in the US alone as of the mid-1990s (half of which are direct health care costs). If a 30% increase took place in the US, the incremental cost of US \$4 billion/year would be on a par with that of a very large hurricane each year.

With a continued rise in atmospheric CO<sub>2</sub> concentrations and early arrival of spring, a significant jump in winter and summer warming (for example, from accelerated release of methane), is accompanied by a stepwise advance in the hydrological cycle, and ensuing growth of weeds, pollen and molds. Additionally, dust

<sup>6</sup> Even in wealthy nations, governments are increasingly seeking to limit their financial exposures to natural disasters. As a case in point, the risk of residential flooding in the US is deemed largely uninsurable, which has given rise to a National Flood Insurance Program (NFIP), with more than 4.2 million policies in force, representing nearly US \$560 billion in coverage. The NFIP pays no more than US \$250,000 per loss per household and US \$500,000 for small businesses.

from areas plagued by persistent drought (the African Sahel and China's Gobi desert) and wildfires alters air quality in many regions of the globe.

Mold and moisture damage had already become a crisis for insurers in some regions (particularly the US in the late 1990s and early 2000s as evidenced by 37,000 claims in Texas alone in the year 2001 (Hartwig 2003). While this was largely due to excessive litigation and media exaggeration, there was also an underlying fact of increased moisture-related losses (up more than four-fold in Texas compared to the prior decade, representing 60% of homeowners' claims value) and changes in construction practices that fostered mold growth.

The increase in infectious diseases (as examples, malaria and West Nile virus) tax existing health infrastructure, particularly in emerging markets. The diseases also have adverse impacts on tourism, which, in turn, slows economic growth and thereby the rate of demand for insurance by the commercial sector (as examples, hotels and factories).

The changing climate alters the prevalence, spatial extent, and type of crop diseases and pests around the globe. A spike in the incidence and range of soybean rust is particularly damaging. Populations of insect herbivores explode in some areas. This is accompanied by a resurgence of preexisting pathogens, and in conditions in which introduced pathogens thrive. Irrigation requirements increase as droughts become more common. Compounding the problem, increased CO<sub>2</sub> contributes to more vigorous weed growth. Worldwide crop losses of approximately 50% of potential yields and stored grains are today attributable to pests. The cumulative effect of multi-year droughts and warm, dry winters (leaving little snowpack) results in bark beetle outbreaks and extensive tree mortality in several regions.

Coral reefs weaken (both physically and biologically) as a result of wind and water movement, thermal stress and biological processes. Significant collapse takes place, compounded by sea level rise, increased storminess and tidal surges, and the associated epidemics of vector-borne diseases. Saltwater intrudes into many aquifers, compromising water quality. Climate change and other impacts of human activities also accelerate the loss of wetlands and other biological barriers to tidal surge damages.

The specific technical outcomes described above have crosscutting impacts on various economic sectors and lines of insurance. For example, vehicular accidents losses increase during inclement weather and heat waves (Munich Re 2005), as well as from floods, windstorms and other catastrophic events. In addition to conventional property losses, business interruptions and associated insurance liabilities also become more common, triggered by extreme weather events and their impacts on energy utilities and other critical infrastructure.

Environmentally displaced persons are mobilized in many parts of the world, putting stress on political risk insurance systems. Insurers experience rising losses as civil unrest and conflicts grow over food, water resources and care for externally and internally displaced persons (Schwartz and Randall 2003).

Contributing to the challenge, existing adaptation methods become less effective. Examples include wildfire suppression, flood defenses, and crop pest controls. In some (but not all) cases, adaptive capacity can be increased, but at considerable cost.

The compounding effects of losses are visible in many lines of the insurance business. The emerging markets are most hard hit, with widespread unavailability or pricing that renders insurance unaffordable. As a result, insurers withdraw from segments of many markets, stranding development projects where financing is contingent on insurance, particularly along coastlines and shorelines vulnerable to sea level rise. Contraction by insurers has direct and indirect dampening effects on economic activity.

Public insurance systems step in to fill the void where commercial insurance is no longer available. They find it difficult to absorb the costs, but, for political reasons, they largely consent to do so. New publicly funded property insurance "backstops" are created for windstorm, wildfire and several other perils. To limit their exposure private insurers establish strict deductibles as well as loss limits, effectively shifting a share of the loss costs back to individuals and businesses. At the end of the 20th century, public crop insurance systems expanded to cover a much larger number of crops than had historically been the case, thereby increasing the exposure to extreme weather events. In the US, for example, over 200 crops were covered under the federal program as of 2005.

Climate impacts are compounded by non-weather factors such as urbanization, though this is also partly a result of migration from drought and disease-ridden rural areas. While the industry may not be bankrupted, as some have suggested, an increasing number of firms do succumb to these losses, especially where solvency regulation is weak. In the US, at least 7% of bankruptcies are currently attributed to catastrophes. As the globe warms, climate change puts a chill on the insurance market. Insurance ceases to be the world's largest industry.

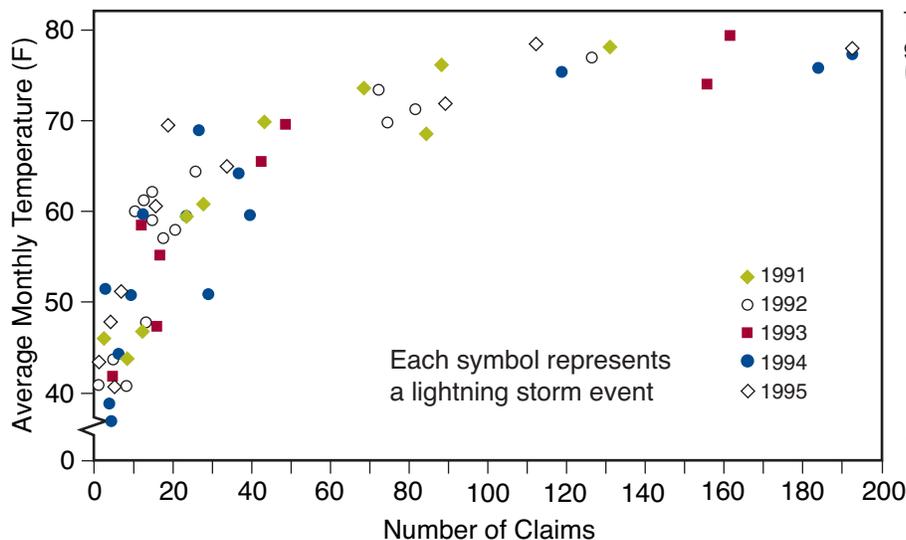


Alternative and more welcome scenarios are certainly also within reach. The measures highlighted in Constructive Roles for the Insurance Sector (following) could go a long way towards reducing the adverse consequences described. Especially in the context of public-private partnerships, the insurance industry could serve as a key agent of both climate change adaptation and reductions in the root causes. The result would include the maintenance of insurability, the preservation of existing markets and the development of new ones. In the best of cases, the insurance industry would prosper through participating in proactive responses to the threat of climate change.



Image: Photodisc

Figure 3.6 Lightning-Related Claims Increase With Temperature



There is a 5-6% increase in air-ground lightning with each 1°F (0.6°C) rise in air temperature.

Source: Richard Jones/Hartford Steam Boiler Insurance and Inspection Service

## CONSTRUCTIVE ROLES FOR INSURERS AND REINSURERS

Although insurance is not a panacea for the problems posed by weather- and climate-related risks — it is only one element in a patchwork of important actors — it can help manage costs that cannot be addressed by international aid or local governments or citizens. In doing so, the insurance industry can play a material role in decreasing the vulnerability to weather-related natural disasters, while simultaneously supporting its market-based objectives and those of sustainable development. This is not new. After all, insurers founded the early fire departments and owned the equipment (Kovacs 2001), helped establish the first building codes and stand behind consumer-safety organizations such as Underwriters Laboratories. Loss prevention is “in the DNA” of the insurance industry.

While insurance is certainly not a “silver bullet,” public-private partnerships can enhance its efficacy as a means of spreading the risks and managing the costs of weather-related disasters and increase the pool of people who have access to it. This is particularly true in the more vulnerable developing countries and economies in transition — the “emerging markets.”

Promising strategies involve establishing innovative insurance products and systems for delivering insurance to the poor, linked with technologies and practices that simultaneously reduce vulnerability to disaster-related insurance losses while supporting sustainable development and reductions in greenhouse gases.

Engagement of the insurance industry could increase the efficacy of sustainable development efforts, while increasing the insurability of risks, thus making new insurance markets more viable (less risky) for insurers.

Emerging markets are especially prone to damages from extreme weather events, given their dependence on the agricultural sector, water availability and on intensive development in low-lying and coastal areas. They can be particularly affected by the spread of disease and degradation of biological systems and by the diversion of scarce resources for relief and recovery. These impacts can deter future investments by increasing the risks faced by foreign interests.

## CHANGING BANK LENDING GUIDELINES

The financial sector, with long time horizons, can be the first sector to sense rising risks and growing instabilities. The financial sector can also change industrial practices through codes and credit lines. Lending guidelines are being revised by several banks, including JP Morgan Chase (Carlton 2005), Citigroup and the Bank of America. The Equator Principles have played a central role in providing guidelines for project financing with regard to greenhouse gas emissions and sustainable forestry. Changes in rules and guidelines by those who extend credit and insurance can ripple through industry, farming, housing and development in general.

Certain measures that integrate climate change mitigation and adaptation can simultaneously support insurers' solvency and profitability (Mills 2005). Promising strategies involve establishing innovative products and systems for delivering insurance and using new technologies and practices that both reduce vulnerability to disaster-related insurance losses and support sustainable development (including reducing greenhouse gas emissions). As one of many examples, curtailing deforestation reduces risks such as wildfire, malaria, mudslides and flooding, while reducing emissions of greenhouse gases. There are also many ways in which renewable energy and energy-efficient technologies reduce risks. For example, distributed power systems reduce the potential for business interruptions caused by damages to the power grid (Mills 2003). An aggressive energy efficiency campaign in California

avoided 50 to 150 hours of rolling blackouts during the summer of 2001 (Goldman et al. 2002). Such integrated strategies call for a fundamental change in economic assessment. While adaptation strategies are typically thought of as having net costs, these strategies also yield mitigation and economic benefits. This is most readily visible in the case of adaptation measures that yield energy savings. For example, a US \$1,000 roof treatment that reduces heat gain (and lowers the risk of mortality during heat catastrophes) may yield US \$200/year in energy savings, resulting in positive cash flow after five years.

Another case in point concerns indoor air quality, in particular aeroallergens such as mold. When the mold issue first arose, insurers, fearing catastrophic and unmanageable losses, excluded coverage (Chen and Vine 1998; 1999). In the interim, insurers have learned more about building science and ways to preempt problems through better building design and operation, with the result that the situation has begun to shift from a "problem" to an "opportunity" (Perry 2005).

Coupling insurance for extreme weather events with strategies that contribute to public health and sustainable development would enhance disaster resilience, and reduce the likely magnitude of losses and, thus, help increase insurers' willingness to establish, maintain, and expand a constructive presence in emerging markets.

## OPTIMIZING STRATEGIES FOR ADAPTATION AND MITIGATION

There are numerous measures being addressed by the IPCC and others to adapt to a changing climate (Smit et al. 2001; Yohe and Tol 2002). The measures discussed under Specific Recommendations for ameliorating the impacts of heat waves can help adapt to climate change and stimulate the development of clean and energy-efficient technologies. Harmonizing measures that reduce vulnerabilities and help to stabilize the climate is a principle that can guide public policy, and guide private investment and insurance policies. There are other examples of strategic measures that provide adaptation and mitigation (primary prevention of climate change; Mills 2002; 2004a).

These include:

- **Energy Efficiency and Renewable Energy:** A host of energy efficient and renewable energy technologies have collateral benefits that enhance adaptive capacity to extreme weather events. Improving the thermal efficiency of the building envelope makes occupants less vulnerable to extreme heat catastrophes and roofs less vulnerable to ice damage.
- **Clean Water Distribution:** Measures for homes, schools, small businesses and agriculture that employ solar and wind power for purifying and pumping water, irrigation, cooking, lighting, and powering small equipment (computers, sewing machines) can have immediate public health and economic benefits (potable water, nutrition, reduced indoor air pollution and a “climate” favorable to economic growth). Such measures can also stimulate internal and international markets in the production of clean energy technologies.
- **Distributed Energy Generation:** Distributed generation (DG) of energy includes on-site generators in homes and institutions, utilizing renewable sources (harnessing solar, wind, tidal and geothermal power), plus fuel cells and combined cycle capture of heat. DG affords increased security from grid failure (for example, from storms and heat-wave-generated blackouts) and provides energy services more efficiently, with lower greenhouse gas emissions. DG can be fostered with lower insurance premiums or other inducements from the financial services sector to reflect the associated risk management value (Mills 2003).

To support such initiatives, insurers would benefit from developing better “intelligence” about changing hazards. The current inability to adequately incorporate current and anticipated climate changes into insurance

Solar Photovoltaic Panels



Image: PowerLight Corporation

business practice traces from disparate efforts to (1) analyze historic trends in climate and extreme weather, (2) model future climates and their impacts and (3) utilize risk information in the insurance business. Practitioners associated with these efforts have divergent orientations and expectations. Loss models also need to do a better job of linking extreme weather events with specific types of insurance. There are some early examples of this type of innovation, which should be studied and expanded upon.<sup>7</sup>

In a changing climate, insurers will no longer have the luxury of basing projections of future losses on past experience (ABI 2004). A central technical challenge is the inability of current models to adequately capture the effects of relevant hazards (see Dailey 2005 regarding winter storms). Another challenge is that interoperability across data sets, models, and sectors is largely lacking. The organizational challenge is that efforts to address the issue are fragmented.

## BENEFITS OF DISTRIBUTED ENERGY GENERATION

The benefits of distributed generation (DG) to complement utility grids include:

- Greater security from grid failure in the face of overload during heat waves or disruption from natural catastrophes.
- Enhanced energy security.
- Decreased cost of and dependence on imported sources of energy for developed and developing nations.
- Helping to jump-start and sustain enterprises that manufacture, distribute and maintain clean energy, and energy-efficient, hybrid and ‘smart’ technologies (computer-run programs that optimize grid response to demand).

<sup>7</sup>For example, AIR Worldwide Corp is linking catastrophe models to estimate insured losses to plate glass as a result of windstorms (Business Insurance 2005).

Industry observers point out that poor data and analysis results in unacceptable costs to insurers, ranging from incorrect pricing, excessive risk-taking, lost business, eroded profitability, as well as regulatory and reputation risks.

The Reinsurance Association of America has noted the opportunity and imperative for integrated assessments of climate change impacts, stating to its constituents, "It is incumbent upon us to assimilate our knowledge of the natural sciences with the actuarial sciences — in our own self interest and in the public interest." (Nutter 1996)

Increased collaboration between the insurance and climate-modeling communities could significantly improve the quality and applicability of data and risk analyses, facilitating availability of insurance in regions where the current lack of information is an obstacle to market development. This potential is exemplified by a shift in

the industry towards accepting flood risks where they previously had been viewed as uninsurable, a sea-change in the perspective of insurers regarding this particular hazard (Swiss Re 2002b).

In the words of Andrew Dlugolecki, on behalf of the Association of British Insurers (2004):

*It is easy to portray climate change as a threat. It certainly poses significant challenges to insurers. But it also offers a range of opportunities, not just in offering new products to meet customers' changing needs, but in keeping the industry at the heart of society, meeting community and national needs whilst properly pursuing profit. Insurers will only be able to provide risk transfer, investment and employment opportunities so long as they are both solvent and generating sufficient margin to invest in the future. This puts a dual duty on insurers: to operate profitably today and to prepare for the future.*

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## SUMMARY OF FINANCIAL SECTOR MEASURES

### I. Climate change is an opportunity for proactive risk management by the insurance industry.

Policies and measures:

- Create new products that increase incentives for behavioral change by business.
- Lobby for regulatory change necessary to reduce risks.
- Insurer participation in the establishment and enforcement of progressive building codes and land-use planning guidelines:
  - The insurance industry was responsible for the first building and fire codes in the US.
- Show industry leadership by expanding the assessment of climate change risks.

### II. However, climate change may also lead insurers to exclude specific events or regions from coverage.

- Those who are emitting CO<sub>2</sub> are not those who are most affected by its results, making it difficult to directly link behavior to premiums.
- New climate risks for health, agriculture, forests and the economy are not yet sufficiently valued to provide specific coverage. Instead, these new risks may require insurers to raise prices or potentially exclude risks that cannot be priced (although regulators have shown strong reluctance to allow this in some cases).
- Insurers in some cases are no longer able to predict future risk based on the past, given increasingly unpredictable weather events and weather patterns.

### III. Multi-faceted risks posed by climate change are a barrier to action, making it challenging to separate and quantify its unique impact on human health.

- The process of climate change and its impacts on human health are interactive and complex, leading to multiple direct and indirect effects for insurers and other businesses.
- Increased uncertainty is of particular concern to insurers.
- Spread of disease, natural disasters, drought, floods, desertification and deforestation are all increasing.

- Social and economic factors in developing countries increase vulnerability to climate change and may lack the capacity to adapt.

**IV. There are some risks that will not affect the bottom line of insurers for the foreseeable future but can have a huge impact on millions of people and the quality of life worldwide.**

- Many of the groups most affected by the growing rate of tropical diseases, such as malaria (that is, the poor in developing countries), are not likely to be insurance clients in the near future.
- Similarly, some of the regions most prone to extreme weather events and environmental degradation are in the developing world — and currently have little or no access to insurance.
- Such uncertainties can affect the climate of investment and impact investment portfolios in the developed and developing world.

**V. Ultimately, to grow their business in an increasingly globalized economy, insurers will need to proactively consider climate change risk in all of their global markets.**

- Risk exclusion strategy will shrink existing markets and reduce insurer ability to pursue high growth in emerging markets, making it an unattractive strategy.
- Emerging markets for insurance are growing at twice the rate of the mature markets.
- Insurers may not have the option of pulling out of markets due to government regulations.
- There may be opportunities to collaborate with the UN and international aid agencies to provide insurance in developing countries, using innovative products such as micro-insurance and micro-finance.
- Government can play the role of insurer of last resort.
- Governments can also provide incentives for insurers to enter new markets.

As a result of the current uncertain environment, society is increasingly vulnerable to new risks that are not presently covered by insurers. The Millennium Development Goals that drive the United Nations programs provide guideposts with which to foster and measure success, and mixed strategies will be needed to manage and reduce risks in the course of achieving those goals.

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Wind Farm



Image: Photodisc

## CONCLUSIONS AND RECOMMENDATIONS

Just as we underestimated the rate at which climate would change, the biological responses to that change and the costs we would incur, we may have underestimated the manifold benefits we can derive from a clean energy transition.

The financial sector — having a long time-horizon and a diversified international portfolio — is the central nervous system of the global economy, sensing disturbances when they begin to percolate in many parts of the globe. Energy lies at the heart of all our activities and all of nature's processes. With the energy infrastructure in trouble, insurers may soon be asking if the future is insurable.

Of the three emerging exposures for the insurance and investment sectors — climate instability, terrorism and tectonic shifts — the first two may be directly or indirectly tied to our dependence on oil. Exiting from the age of oil is the first and necessary step toward improving the environment and our security and achieving sustainable development (Epstein and Selber 2002).

Together, finance, UN agencies, scientists and civil society can seize the opportunities. The combination of a) focused lending and investment, b) targeted insurance coverage, and c) sufficient economic incentives from governments and international financial institutions can jump-start “infant” industries and sustain an economically productive, clean energy transition.

## POLICIES AND MEASURES

The global nature of the problems associated with a rapidly changing climate often seems overwhelming. Multiple measures at various levels are required, but the political will to undertake them is often difficult to initiate, much less sustain. Coordinating actions by various stakeholders can be particularly daunting.

Yet change is necessary, and involvement of all sectors of society is needed. With careful steering and an expansive dialogue, societies can reduce risks and benefit from the opportunities. With this in mind, the editors and authors of this report have divided proposals into two categories — fostering awareness and taking action.

## FOSTERING AWARENESS OF CARBON RISKS, EXPOSURES AND OPPORTUNITIES

Understanding the risks and opportunities posed by climate change and sensitizing others is the first step towards taking corrective measures. A broad educational program is needed to better inform businesses, regulators, governments, international bodies and the public as to the science and impacts of climate change. The health of large regional and global ecosystems that support us is at stake.

Regulators and governments need to understand the science in order to frame regulations in climate-friendly ways. Special attention should be given to identifying misaligned incentives and market signals that perpetuate environmentally destructive practices.

Firms can better understand their own exposures to the physical and emerging business risks — including litigation, legislation, shifts in consumer choices and activism within civil society. In the energy transition ahead, companies can identify ways to profitably address the challenges.

For insurers, climate change challenges all aspects of their core business, including property and casualty, life and health, and financial services. Insurers can amass more pertinent information on climate risks as the past becomes a less informative predictor of the future and share this knowledge with other stakeholders through interactive dialogues.

Investors and financial analysts can evaluate portfolios for climate risks and opportunities, and capital market professionals can add climate screens to their study of balance sheets and market possibilities. Capital markets sometimes miss the “signals” coming from climate, paying attention only to large, obvious events such as hurricanes and typhoons.

And citizens can learn about their own carbon footprint — the amount of carbon their own activities release into the environment — driven by their consumption patterns and political choices. Civil society has a central role to play in building awareness in all sectors and helping businesses, governments and international financial institutions formulate measures for fundamental change to achieve clean and sustainable development.

Finally, new technologies need to be clean and safe. Those intended to adapt to climate change and disease, such as genetically modified organisms, need to be fully evaluated as to their implications for natural systems. Those aimed at climate mitigation, including carbon sequestration, coal gasification and expanded use of nuclear power, must undergo thorough scrutiny regarding their repercussions for health, ecology and economies. Life cycle analysis of proposed solutions can form the basis of those assessments.

### ACTION: SEIZING OPPORTUNITIES AND CUTTING CARBON EMISSIONS

The next step is reducing the output of greenhouse gases, and this will require concerted efforts by all stakeholders. A framework for solutions is the following:

- Significant, financial incentives for businesses and consumers.
- Elimination of perverse incentives (Myers and Kent 1997) that subsidize carbon-based fuels and environmentally destructive practices.
- A regulatory and institutional framework designed to promote sustainable use of resources and constrain the generation of wastes.

A set of integrated, reinforcing policy measures is needed. The chief issue is the order of magnitude of the response. The Kyoto Protocol calls for 6-7% reduction of carbon emissions below 1990 levels by 2012, while the IPCC calculates that a 60-70% reduction in emissions is necessary to stabilize atmospheric concentrations. How large an investment we make in our common future will be a function of the educational process and how rapidly the reality of climate change affects our lives.

The scenario process enables us to envision a future with widespread impacts and even climate shocks (such as slippage of portions of Greenland).

"Imagining the unmanageable" can help us take constructive steps in the short term, while making contingency plans for even bolder, more rapid transformations in the future.

Each sector can play a part and develop partnerships to catalyze progress. Individuals and the institutions in which they are active (schools, religious institutions, workplaces, communities and municipalities) can make consumption decisions and political choices that influence how our future unfolds.

Corporate executive managements can declare their commitment to principles of sustainability, such as those of Ceres and the Carbon Disclosure Project, and develop codes, such as those enunciated by the Equator Principles, to guide financial institutions in assessing climate-related risks and specifying environmental and social risks in project financing. Firms can make their own facilities energy-efficient and encourage carbon-reducing measures, such as telecommuting and the use of virtual business tools.

An enormous challenge — that can spawn many economic activities — is the task of ecological restoration. Large programs are needed to restore Florida's ecosystems and the Gulf coast's barrier wetlands and islands. Other industries will be needed to construct buildings and new infrastructure, improve transport systems and plan cities to meet the requirements of the coming climate.

Governments, in partnerships with international organizations and businesses, can help transfer new technologies and manufacturing capability to developing nations. Encouraging consumers to purchase products that set aside part of the price to pursue climate friendly ('footprint neutral') projects is just one commercial innovation being developed. The global sharing of best practices can help reduce the number and intensity of resource wars that may loom if only temporizing measures are adopted.

Insurers, along with their clients, can facilitate development of low carbon technologies through their policies and new products and can set the pace for others striving to become greenhouse gas neutral. Risk perception can be an obstacle to adopting new technologies, and the insurance industry can influence commercial behavior by creating products that transfer some of the risk away from investors. It was insurance coverage only for buildings with sprinkler systems, for example, that enabled the construction of skyscrapers in the early 20th century. Policies today could help redirect society's future energy diet and speed development of beneficial technologies.

Investors at all levels, and especially institutional investors such as state and union pension funds, can direct capital toward renewable energy technologies. Project finance and new financial instruments can provide stimulus for solar, wind, geothermal, tidal and hybrid technologies and help drive the clean energy transition. Capital markets can foster the development

# FINANCIAL INSTRUMENTS

Regulators and governments can create a sound policy framework and make use of market mechanisms. Such measures include:

- Standards of energy efficiency for vehicles, appliances, buildings and city planning to jump-start infant industries and sustain the growth of others.
- A regulatory framework for carbon.
- Financing public programs that foster low-carbon technologies.
- Altering procurement practices to help create new demand.
- Optimizing interest rates at a level that best benefit consumers, industry and finance.
- Making a large investment of public dollars in the new energy infrastructure.

## **Positive incentive options:**

- Tax incentives for producers and consumers.
- Subsidies to prime new technologies.
- International clean development funds to:
  - transfer new technologies.
  - protect common resources (forests, watersheds, marine habitats).

## **Negative incentive options:**

- Carbon taxes that discourage fossil fuel use and generate funds.
- Currency trading taxes that encourage long-term investment and generate funds.

## **“Perverse” incentives that need to be reevaluated:**

- Subsidies and tax breaks for oil and coal exploration.
- Debts, unequal terms of trade and “conditionalities” for aid that undermine support for public services, trained personnel, research and sustainable environmental practices.

## **Indirect incentives:**

- Carbon trading.
- Trading in derivatives.

# BRETTON WOODS 1944: WHAT COMES NEXT?

With Europe in shambles after two world wars and the Great Depression, world leaders gathered in 1944 at the Bretton Woods conference center in the White Mountains of New Hampshire to plot out a new world order. New rules, incentives and institutions were needed. The League of Nations established in Paris in 1919 after World War I had been inadequate to prevent subsequent global conflict. Under the leadership of Sir John Maynard Keynes, the delegates crafted a new development paradigm.

Three new rules were agreed upon:

1. Free trade in goods.
2. Constrained trade in capital.
3. Fixed exchange rates.

New institutions were established:

1. The International Bank for Reconstruction and Development (The World Bank).
2. The International Monetary Fund.

In the same period, Eleanor Roosevelt shepherded in the Universal Declaration of Human Rights setting new standards and goals, and the United Nations was formed.

The financial incentives that followed proved to be the necessary component.

The Marshall Plan provided funds to rebuild Europe and regenerate robust trading partners. In the US, the GI Bill stimulated housing construction, new colleges, job training and jobs that combined to prime sustained growth in the post-war period.

In 1972, however, the Bretton Woods rules came undone. Mounting outlays for the Vietnam War strained US fiscal balances, precipitating the abandonment of the second and third rules: Capital as well as goods could now be moved freely and currencies were allowed to float. The result was that, following the OPEC oil embargo, oil prices increased tenfold from US \$3 a barrel to US \$30, and gold shot up from US \$38 to over US \$600. Save for nations endowed with “black” or yellow gold, numerous nations dependent on oil to power their farms, industries and transport became bankrupt.

With loans from international financial institutions to purchase oil and fund huge hydropower schemes (that unknowingly spread diseases, such as malaria and snail-borne schistosomiasis), many nations slipped deeper into debt and cleared forests to plant crops to export food to meet debt payments. The projected “epidemiological transition” associated with development — from tropical diseases and malnutrition to the ills more prevalent in developed nations (such as heart disease, diabetes and cancer) — failed to occur for most sectors of the developing world.

By 1983, the lines had crossed: More money was flowing out of the developing world than was flowing in, and the debt crisis, rising inflation and belt-tightening conditions placed on subsequent loans undermined public sectors and weakened many nation states.

In the 1990s growth in information technology in developed nations skyrocketed, as did the speculative trade in currencies. (Currency transactions went from US \$18 billion a day in 1972 to US \$1.9 trillion daily today.) Then the market bubble burst.



Will today’s confluence of environmental, energy and economic crises lead to a conscious restructuring of development priorities? One hundred and fifty years ago urban epidemics of cholera, TB and smallpox drove environmental reform, modern sanitation and the creation of clean water systems. Will public health and well being resume their center-stage roles as the drivers for development? With laissez-faire we risk collapse or, worse, an authoritarian response to scarcity and conflict. The alternative is a future rich with innovation and sustained, healthy growth.

How we develop and how we power that development are the pivotal decisions. Making the decisions democratically will mean including stakeholders that were not included in Bretton Woods — women, civil society and developing nations. Finance — with its globally diversified portfolio, monetary instruments and political influence — has a unique role to play in this transition. Having appreciated the long-term trajectory of expanding risk profiles, the financial services sector, with civil society and the United Nations, can convene the discussions to how best construct the scaffolding for a more stable and sustainably productive future (Epstein and Guest 2005).

of carbon-risk hedging products, such as derivatives, and promote secondary markets in carbon securities. Carbon trading can potentially become a separate revenue stream for carbon producers, energy-efficient companies and poor nations, and open the door to carbon-offsetting products that may become growth industries in a carbon-constrained future.

Scientists can model early warning systems to help the public and industry reduce anticipated damages. With the proper incentive and reward structure, researchers can focus their ingenuity on the collaborative development of climate-friendly technologies. Governments and international bodies have central roles to play in stimulating public/private partnerships and in carrying out an expanded program of basic and applied research to make alternative and energy-efficient technologies effective and inexpensive.

## PLANNING AHEAD

Climate may change in gradual and manageable ways. But it may also bring major surprises. The good news is that unstable systems can be restabilized.

Planning is needed to prepare for future catastrophic events and the “inevitable surprises” that climate change will bring (NAS 2002). We must be prepared to respond rapidly to such events to limit the damages and minimize the casualties. And we must also prepare to put in place financial mechanisms to implement large-scale solutions that can restabilize the climate.

At some points in history, efforts have been made to deliberately manage the goals and key drivers of development. The Berlin Conference of 1884 was such a moment, but the divisive agreements set nations apart and seeded subsequent conflict. Another point came in 1944, when world leaders convened a conference in Bretton Woods, NH, and established a world order with much more positive outcomes (see sidebar on Page 110).

A properly financed transition out of the fossil fuel era can have enormous public health, environmental and economic benefits, and can lay the basis for far greater international security and global stability. The challenge of climate change presents an opportunity to build a clean and healthy engine of growth for the 21st century.

Appendix A. Summary Table of Extreme Weather Events and Impacts

Type of event relevant to insurance sector	Changes in extreme climate phenomena	Likelihood*		Sensitive sectors / Activities	Sensitive insurance branches (high confidence)**
		Observed changes	Projected changes		
<b>Temperature extremes</b>					
Heat wave	Higher maximum temperatures, more hot days and heat waves*** over nearly all land areas	Likely *, (mixed trends for heatwaves in several regions)	Very likely*	Electric reliability, human settlements	Health, life, property, business interruption
Heat waves, droughts, permafrost melt				Forests (tree health), natural resources, agriculture, water resources, electricity demand and reliability, industry, health, tourism	Health, crop, business interruption
Frost, frost heave	Higher [Increasing] minimum temperatures, fewer cold days, frost days and cold waves*** over nearly all land areas	Very Likely *, (cold waves not treated by WG1)	Very likely*	Agriculture, energy demand, health, transport, human settlements	Health, crop, property, business interruption, vehicle
<b>Rainfall/precipitation extremes</b>					
Flash flood	More intense precipitation events	Likely * over many Northern Hemisphere mid- to high latitude land areas	Very likely*, over many areas	Human settlements	Property, flood, vehicle, business interruption, life, health
Flood, inundation, mudslide				Agriculture, forests, transport, water quality, human settlements, tourism	Property, flood, crop, marine, business interruption
Summer drought, land subsidence, wildfire	Increased summer drying and associated risk of drought	Likely*, in a few areas	Likely* over most midlatitude continental interiors (lack of consistent projections in other areas)	Forests (tree health), natural resources, agriculture, water resources, (hydro) energy supply, human settlements	Crop, property, health
Snowstorm, ice storm, avalanche	Increased intensity of midlatitude storms***	Medium likelihood* of increase in Northern Hemisphere, decrease in Southern Hemisphere	Little agreement among current models	Forests, agriculture, energy distribution and reliability, human settlements, mortality, tourism	Property, crop, vehicle, aviation, life, business interruption
Hailstorm				Agriculture, property	Crop, vehicle, property, aviation
Drought and floods	Intensified droughts and floods associated with El Niño events in many different regions [See also under droughts and extreme precipitation events]	Inconclusive information	Likely*	Forests (tree health), natural resources, agriculture, water resources, (hydro) energy supply, human settlements	Property, flood, vehicle, crop, marine, business interruption, life, health
<b>Wind extremes</b>					
Midlatitude windstorm	Increased intensity of midlatitude storms***	No compelling evidence for change	Little agreement between current models	Forests, electricity distribution and reliability, human settlements	Property, vehicle, aviation, marine, business interruption, life
Tornadoes				Forests, electricity distribution and reliability, human settlements	Property, vehicle, aviation, marine, business interruption
Tropical storms, including cyclones, hurricanes and typhoons <sup>9</sup>	Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities****	Wind extremes not observed in the few analyses available; Insufficient data for precipitation	Likely*, over some areas	Forests, electricity distribution and reliability, human settlements, agriculture	Property, vehicle, aviation, marine, business interruption, life

Summary Table of Extreme Weather Events and Impacts (continued)

Extreme climate-related phenomena and their effects on the insurance industry: observed changes and projected changes during the 21<sup>st</sup> century. (After Table 3-10 in IPCC/TAR/WG2/Chapter 3, and Munich Re, 1999b, p. 106).

Type of event relevant to insurance sector	Changes in extreme climate phenomena	Likelihood*		Sensitive sectors / Activities	Sensitive insurance branches (high confidence)**
		Observed changes	Projected changes		
<b>Other extremes</b>					
Lightning <sup>10</sup>	Refer to entries above for higher temperatures, increased tropical and midlatitude storms	Refer to relevant entries above	Refer to relevant entries above	Electricity distribution and reliability, human settlements, wildfire	Life, property, vehicle, aviation, marine, business interruption
Tidal surge (in association with onshore gales), coastal inundation	Refer to entries above for increased tropical cyclones, Asian summer monsoon, and intensity of midlatitude storms	Refer to relevant entries above	Refer to relevant entries above	Coastal zone infrastructure, agriculture and industry, tourism	Life, marine, property, crop
Flood and drought	Increased Asian summer monsoon precipitation variability	Not treated by WG I	Likely*	Agriculture, human settlements	Crop, property, health, life
Elevated atmospheric CO <sub>2</sub>	Increased pollen production	Not treated by WG I	Very likely*	Asthma and other respiratory disease	Health

Note: Adapted from IPCC (Vellinga et al. 2001); last row (elevated CO<sub>2</sub>) not included in original version.

\* Likelihood refers to judgmental estimates of confidence used by Working Group I: very likely (90-99% chance); likely (66-90% chance). Unless otherwise stated, information on climate phenomena is taken from Working Group I, Summary for Policymakers and Technical Summary. These likelihoods refer to the observed and projected changes in extreme climate phenomena and likelihood shown in columns 1 to 3 of this table.

\*\* High confidence refers to probabilities between 2-in-3 and 95% as described in Footnote 4 of SPM WGII.

\*\*\* Information from Working Group I Technical Summary, Section F.5.

\*\*\*\* Changes in regional distribution of tropical cyclones are possible but have not been established.

## APPENDIX B.

### ADDITIONAL FINDINGS AND METHODS FOR US ANALOG STUDIES OF HEAT WAVES

This appendix covers the details of the heat wave case study and the methods used to carry out the analog studies for five US cities.

Maximum and minimum temperatures are equally important in understanding the oppressive nature of the heat wave during the analog summer. For 24 days nighttime temperatures tie or break high minimum temperature records, and for 11 days they tie or break the all-time high minimum temperature record of 28°C (82°F). Eight of the 11 days are consecutive, and such a string would undoubtedly have a very negative impact on the population of the city.

In Washington, DC, 11 days record maximum temperatures at or above 41°C (105°F). However, the most intense heat for the analog summer occurs in St. Louis, where an all-time maximum temperature record of 46°C (116°F) is achieved on July 14 plus 8 days record temperatures of 44°C (110°F) or higher. Some minimum temperatures never fall below 32°C (90°F), and an all-time high minimum temperature record of 34°C (93°F) is set on August 9 in St. Louis.

The normally cooler cities of New York City and Detroit are not spared in the analog event. For New York, four days break the all-time maximum temperature record and two days achieve the same for minimums. One day reaches 44°C (110°F) and 11 straight days in August have minimums exceeding 27°C (80°F). Detroit breaks two all-time maximums, and has a string of seven out of eight days breaking all-time minimums. Fourteen days in Detroit exceed 38°C (100°F) during the analog summer, including a nine-day consecutive string in August.

#### Methods

First, the Paris event is characterized statistically, and these characteristics are transferred to the selected US cities. Second, the hypothetical meteorological data-set for each city is converted into a daily air mass calendar through use of the spatial synoptic classification. A large body of literature suggests that humans respond negatively to certain “offensive air masses,” which envelop the body during stressful conditions (Kalkstein et al. 1996; Sheridan and Kalkstein 2004). Rather than responding to individual weather elements, we are affected by the simultaneous impact of a much larger suite of meteorological conditions that constitute an air mass.

The spatial synoptic classifications are based on measurements of temperature, dew point temperature, pressure, wind speed and direction, and cloud cover to classify the weather for a given day into one of a series of predetermined, readily identifiable, air mass categories. They are:

- |                      |                              |
|----------------------|------------------------------|
| 1. Dry Polar (DP)    | 5. Moist Moderate (MM)       |
| 2. Dry Moderate (DM) | 6. Moist Tropical (MT)       |
| 3. Dry Tropical (DT) | 7. Moist Tropical Plus (MT+) |
| 4. Moist Polar (MP)  |                              |

An evaluation of the air mass frequencies for the analogs to the 2003 Paris heat wave in the five US cities provides a clear picture of how exceptional this event would be (Table B.1). On average, Philadelphia, for example, experiences offensive air masses MT+ or DT in June, July, and August, 15.2%, 16.5%, and 11.3% of the time, respectively (or 14.3% averaged over the three-month summer period). Applying the 2003 analog to Philadelphia, these values increase to 50%, 38.7% and 58%, respectively.

Table B.1 Summer Percentage Frequencies of Offensive Air Mass<sup>A</sup> Days for the Five Cities

City	Average <sup>B</sup>	Analog	Difference: Analog vs. Average	Hottest Summer	Difference: Analog vs. Hottest Summer
Detroit	9.2%	48.9%	431.5%	38.0%	28.7%
New York	11.2%	48.9%	336.6%	26.1%	87.3%
Philadelphia	14.3%	48.9%	242.0%	41.3%	18.4%
St. Louis	17.7%	48.9%	176.2%	42.4%	15.3%
Washington, DC	13.7%	48.9%	256.9%	34.8%	40.5%

<sup>A</sup> Offensive air masses are MT+ and DT.

<sup>B</sup> Average for period 1945-2003.

Source: Sheridan, 2005.

Table B.2 Heat-Related Mortality During the Average, Analog, and Hottest Historical Summers

	Detroit	New York	Philadelphia	St. Louis	Washington
Metropolitan area population <sup>A</sup>	4.4 million	9.3 million	5.1 million	2.6 million	4.9 million
Average summer heat- related mortality <sup>B</sup>	47	470	86	216	81
Average summer mortality rate per 100,000 population	1.07	5.05	1.69	8.30	1.65
Analog summer heat- related mortality	582	2,747	450	627	283
Analog summer mortality rate per 100,000 population	13.23	29.54	8.82	24.12	5.78
Hottest historical summer mortality <sup>C</sup>	308	1,277	412	533	188
Hottest historical summer mortality rate per 100,000 population	7.00	13.73	8.08	20.50	3.84
Year of hottest historical summer occurrence	1988	1995	1995	1988	1980
Analog percent deaths above hottest historical summer	89.0	115.1	9.2	17.6	50.5

<sup>A</sup> Based on 2000 U.S. Census Bureau data.

<sup>B</sup> Numbers represent revised values.

<sup>C</sup> Based on a period from 1961-1995.

The number of consecutive days within offensive air masses is also very unusual for the analog summer. There are two very long consecutive day strings of MT+ and DT air masses: from July 10 through July 22 and from August 2 through August 17. Using Washington, DC, as an example, in 1995, the hottest summer during the 59-year historic period, there were 12 offensive air mass days between July 14 and August 4, but no more than 3 of these days were consecutive. In Philadelphia, the 1995 heat wave was more severe than in Washington, DC, yet in terms of consecutive days, it was still far less extreme than the analog summer. From July 13 to August 4, 1995, there were 20 offensive air mass days, but with several breaks when non-offensive air mass days lasted at least two days.

Maximum and minimum temperatures during the analog summer are far in excess of anything that has occurred in recorded history. Using Philadelphia as an example again, 15 days recorded maximum temperatures that exceed 38°C (100°F) during the analog summer. On average, such an extreme event occurs less than once a year. During the hottest-recorded summer over the past 59 years, 1995, this threshold was reached only once. Fifteen days in the analog summer break maximum temperature records, and from August 4 to August 13, nine of the ten days break records. In addition, four days break the all-time maximum temperature record for Philadelphia, 41°C (106°F), with three of these occurring during the 10-day span in August.

## APPENDIX C. FINANCE: PROPERTY INSURANCE DYNAMICS

Overall costs from catastrophic weather-related events rose from an average of US \$4 billion per year during the 1950s, to US \$46 billion per year in the 1990s, and almost double that in 2004. In 2004, the combined weather-related losses from catastrophic and small events were US \$107 billion, setting a new record. (Total losses in 2004, including non-weather-related losses, were US \$123 billion; Swiss Re 2005a). With Hurricanes Katrina and Rita, 2005 had, by September, broken all-time records yet again. Meanwhile, the insured percentage of catastrophic losses nearly tripled from 11% in the 1960s to 26% in the 1990s and reached 42% (US \$44.6 billion) in 2004 (all values inflation-corrected to 2004 dollars, Munich Re NatCatSERVICE).

**Damage to Physical Structures and Other Stationary Property:** The current pattern of increasing property losses due to catastrophic events — averaging approximately US \$20 billion/year in the 1990s — continues to rise steadily (Swiss Re 2005). Assuming that trends observed over the past 50 years continue, average annual insured losses reach US \$50 billion (in US \$2004 dollars) by the year 2025.<sup>2</sup> Peak-year losses are significantly higher. The industry largely expects this and does its best to maintain adequate reserves and loss-prevention programs. The industry is caught unawares, however, by an equally large number of losses from relatively “small-scale” or gradual events that are not captured by insurance monitoring systems such as Property Claims Services (which only tabulates losses from events causing over US \$25 million in insurance claims). Data on these relatively small losses collected by Munich Re between 1985 and 1999 indicate that such losses are collectively equal in magnitude to those from catastrophic events (Vellinga et al. 2001).<sup>3</sup> These include weather-related events such as lightning strikes<sup>4</sup> (which cause fires as well as damages to electronic infrastructure), vehicle accidents from inclement weather, soil subsidence that causes insured damages to structures, local wind and hailstorms, etc. Sea level rise, changes in the patterns of infectious diseases, and the erosion of air and water quality are important classes of gradual events and impacts, the consequences of which are also not captured by statistics on extreme events. Losses from these small-scale events grow as rapidly as those for catastrophic events, with disproportionately more impact on primary insurers than on reinsurers (who commonly offer only “excess” layers of coverage beyond a contractually agreed trigger level).

<sup>1</sup> Source: Munich Re NatCatService.

<sup>2</sup> This is generally consistent with the global projection made by the UNEP-Finance Initiative and Innovest (2002), and by the Association of British Insurers (2004) for the UK.

<sup>3</sup> Even this estimate is conservative, as not all losses are captured by this more inclusive approach.

<sup>4</sup> Lightning has been cited as responsible for insurance (presumably property) claims (Kithil 1995), but estimates vary widely. St. Paul Insurance Co. reported paying an average 5% of US \$332 million in lightning-related claims annually between 1992 and 1996 (Kithil 2000). The portion of these costs that are related to electricity disturbances is not known. One report from the Department of Energy states that of the lightning-related losses experienced at its own facilities, 80% were due to voltage surges (Kithil 2000). Hartford Steam Boiler Insurance & Inspection Co. has observed that claims are far more common during warm periods. This is corroborated by Schultz (1999). In addition to these losses, lightning strikes are responsible for 85% of the area burned by wildfires (Kovacs 2001).

Climate sensitivity for small-scale events can be quite high. For example, for every increase in average temperatures of 1°C we expect a 70% increase in air-to-ground lightning strikes (Reeve and Toumi 1999).

**Personal Automobile Insurance:** The impact of catastrophes on automobile losses began to become visible during the 1980s and 1990s, but these understate the true extent of the losses because only those losses from catastrophic events were tabulated in association with inclement weather. As the incidence of small storms increases, roadway conditions can erode and there are more days with low visibility, icy conditions, and precipitation, resulting in a steady increase of accidents.

**Energy and Water Utility Systems:** Increasingly extensive and interconnected energy and other systems enhance the quality of life, but also increase society's vulnerability to natural hazards (Sullivan 2003). Energy systems are already experiencing rising losses. Under accelerated, non-linear climate change, there are increased damages to energy and water industry infrastructure, including ruptured oil and electricity transmission systems due to widespread permafrost melt throughout the northern latitudes, and risks to power plants. Increased extreme weather events, such as ice storms and heat catastrophes, cause increased numbers of blackouts and water contamination or direct damages to water plants.

The following are several examples of the nature of energy system sensitivities to extreme weather events (Munich Re 2003):

- The US northeast Ice Storm of 1998 was the most expensive disaster in the history of the Canadian insurance industry.
- In 1998, on the other side of the world in Auckland, New Zealand, the most severe heat wave since 1868 caused spikes in air-conditioning power demand and the overloading and subsequent collapse of two electricity transmission cable lines.
- In 1999, a flash of lightning plunged more than 80 million people in Sao Paulo and Rio de Janeiro, and eight other Brazilian states into darkness. Two years later, a prolonged drought — the worst in 70 years — led to a national power crisis, with rationing lasting nearly nine months.
- In 1999, the great windstorms caused EU2.5 billion in damages to France's largest electricity supplier.
- In 1982, a shortage of rain forced deep load shedding in Ghana. Impacts included business interruptions of US \$557 million at an aluminum smelter.
- In 1993, the Des Moines Water Works was shut down due to flooding. Direct property damages and emergency measures were US \$16 million, but the indirect business interruption losses resulted in 250,000 commercial and residential customers being without water for 11 days.

A particularly diverse set of risks apply in the electricity sector (Mills 2001). The current US baseline cost of electrical outages of US \$80 billion per year (LaCommare and Eto 2004) could double under our scenarios. In our scenarios, businesses seek increasing business-interruption coverage for such events, and a larger share of consequent losses is paid by insurers. In addition, increasingly frequent drought conditions result in power curtailments that cause further business interruptions in regions heavily dependent on hydroelectric power. Drought plus unacceptably higher cooling water temperatures in summer 2003 forced curtailments or closures of nuclear and other thermal plants in France, Germany, Romania and Croatia and price spikes in addition (Reuters 2003, Guardian 2003). Massive oil-sector losses such as those caused by Hurricane Ivan (approximately US \$2.5 billion, well in excess of the year's entire premium revenue for the sector)<sup>5</sup> (Miller 2004), would become more common. Premiums for vulnerable oil infrastructure were projected to double after this event, and consumers faced higher prices due to the 500,000 barrel per day supply shortfall (The Energy Daily 2004a). Emblematic of the industry's history of underestimating its exposures, a representative of Hiscox Syndicates in London stated that "the market has had a much worse loss than ever anticipated." Electric utilities were also hard hit, with one utility's costs reaching US \$252 million (The Energy Daily 2004b).

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<sup>5</sup> Hurricane Ivan destroyed seven oil platforms, damaged six others as well as five drilling platforms, and pipelines were buried by underwater mudslides in the Mississippi Delta. In Hurricanes Katrina and Rita, 109 off-shore oil rigs were destroyed and 31 severely damaged.

**Crop and Timber Insurance:** Crop insurance and reinsurance is provided by a mix of public and private mechanisms. The US government program covers 350 commodities through 22 specific insurance programs and assumes about US \$40 billion in insured values. The public crop insurance system already tends to pay out more in losses than it collects in premiums, and rising losses would more deeply erode the system's viability, especially in a political environment in which increased taxes (which ultimately finance the system) are not politically desirable. As an example for a single crop in a single country, Rosenzweig et al. (2002) estimate a doubling of current corn losses to US \$3 billion/year under intermediate (30-year) climate change.

The current structural expansion of the program to include more and more perishable products as well as livestock increases the vulnerability of the sector to extreme weather events.

In our business scenarios, losses continue to rise, prices of government-provided insurance are increased, deductibles increased, and payout limits are reduced in most areas, and completely eliminated in others (for example, for drought-prone crops). One consequence for the insurance sector is that administrative fees it currently receives for delivering the government insurance are lost. Furthermore, the resulting contraction in the agricultural sector reduces the number and size of firms seeking other insurance products (for example, property and workers' compensation). A more minor line of coverage, losses for "standing timber insurance," increases due to the combination of wildfire and insect-related damages.

More than 5 billion board feet of timber had been lost to spruce beetles as of 1999.<sup>6</sup> In an assessment of the risks in California, wildfire-related losses are predicted to double on average (and increase up to fourfold in some areas). Superinfestations continue to be a problem leading to multiple losses, ranging from timber to property to the health consequences of increased airborne particulates from wildfires.

## LIABILITY INSURANCE DYNAMICS

**Corporate Liability:** Liability risks can manifest under climate change as a result of responses of various parties to the perceived threat (Allen and Lord 2004). For example, Attorneys General from NY, CA, CT, ME, NJ, RI, and VT are suing utilities to force 3% annual reduction of GHG emissions over 10 years. State Treasurers from CA, CT, ME, NM, NY, OR and VT called for disclosure of financial risks of global warming in securities filings (Skinner 2004). Environmental groups and cities have brought suits against US federal agencies for supporting fossil fuel export projects without assessing their impacts on global climate (ABI 2004). In our scenarios, this trend accelerates in the early part of the 21<sup>st</sup> century.

**Environmental Liability:** Extreme weather events can lead to a rise in local pollution episodes, triggering environmental liability insurance claims. Following the Mississippi River floods of 1993 there was extensive polluted water runoff from pig farms, affecting drinking water supplies. Hurricanes Katrina and Rita led to massive contamination with petrochemicals, pesticides, heavy metals and microorganisms.

## LIFE-HEALTH INSURANCE DYNAMICS

Remarkably, the insured costs associated with health and loss of life from natural disasters are not known or tracked by the industry. Charts such as figure 1.5 exclude such information. This is largely because the losses are

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<sup>6</sup> According to Holsten et al. (1999): "The spruce beetle, *Dendroctonus rufipennis*, Kirby, is the most significant natural mortality agent of mature spruce. Outbreaks of this beetle have caused extensive spruce mortality from Alaska to Arizona and have occurred in every forest with substantial spruce stands. Spruce beetle damage results in the loss of 333 to 500 million board feet of spruce saw timber annually. More than 2.3 million acres of spruce forests have been infested in Alaska in seven years [1992-1999] an estimated 30 million trees were killed per year at the peak of the outbreak. In the 1990s, spruce beetle outbreaks in Utah infested more than 122,000 acres and killed more than 3,000,000 spruce trees. In the past 25 years, outbreaks have resulted in estimated losses of more than 25 million board feet in Montana, 31 million in Idaho, over 100 million in Arizona, 2 billion in Alaska, and 3 billion in British Columbia."

diffuse and do not manifest in single “catastrophe” events. The lack of information is worrisome, as the industry lacks good grasp of its exposure as it does in the property/casualty lines. Life insurance “catastrophes” were unknown for insurers prior to 9/11 and the massive heat mortality in Europe in summer 2003. To provide a frame of reference, ING Re’s Group Life estimates that a pandemic like that of 1918-1919 would result in a doubling of group life payouts in the US alone of approximately US \$30 billion to US \$40 billion per year (Rasmussen 2005). Given that the US has about one-third of the world market in life insurance, this would imply US \$90 billion to US \$120 billion per year globally.

Respiratory disease emerges as one of the most pervasive health impacts of climate change and the combustion of fossil fuels. One driver is an elevated rate of aeroallergens from more CO<sub>2</sub> — that is predetermined to rise regardless of the energy trajectory, given the 100-year life time of these molecules in the atmosphere. Asthma, already a major and growing challenge for insurers in the late 20th century, becomes more widespread. This is accompanied by an upturn in mold-related claims due to increased moisture levels in and around buildings. Exacerbating the problem, a variety of sources of increased airborne particulates (particularly PM<sub>2.5</sub>, the fine particulate matter equal to or less than 2.5 micrometers) also impact respiratory health and these arise from an increased frequency of wildfires, major and minor dust storms associated with droughts and changing wind patterns, and air pollution patterns.

Heat catastrophes are projected to become a growing issue throughout the world. This will increase mortality and, along with water shortages, affect wildlife and livestock, forests and soils, and will put added stresses on already stretched energy demands, generating additional greenhouse gases, without major changes in the sources of energy.

Infectious diseases are afflicting a wide taxonomic range. In terms of human morbidity and mortality and ecosystem health and integrity, the role of infectious diseases is projected to increase in industrialized and in underdeveloped regions of the world, adding substantially to the accelerating spread of disease, and the loss of species and biological impoverishment.

In our scenarios, an array of other health problems become more prevalent in industrialized countries, although socioeconomic buffers and public health interventions may buffer the impacts in the short-term. Food poisoning due to spoilage — now a summertime phenomenon — can increase with more heat spells. Weather-related roadway accidents can increase as do an assortment of ills related to eroded water quality. There are also increased rates of physical damage and drownings under our scenarios arising from natural catastrophes such as windstorms and floods.

Under our scenarios, each of the above-mentioned developments is amplified considerably in developing nations and in economies in transition (the emerging markets). Health and life insurance grows rapidly in these regions during the early part of the 21st century, but is slowed as insurers recognize the increasing losses and withdraw from these markets, or raise prices to levels at which their products becomes unaffordable.

Table C. Standards of "Insurability" with Regard to Global Climate Change

Conditions Contributing to Insurability	Means of Achieving Insurability
<b>Assessable Risk:</b> Insurers must understand the likelihood and estimated magnitude of future claims and be able to unambiguously measure the loss. This is essential for pricing, especially where regulators require that premiums be based strictly on historic experience (rather than projections). For example, some insurers and reinsurers currently avoid Asia and South America but have expressed interest in expanding into these regions if loss and exposure information become more available (Bradford 2002).	<ul style="list-style-type: none"> <li>• Improved data (e.g., flood zone mapping) and climate/impact modeling for developing countries and economies in transition.</li> </ul>
<b>Randomness:</b> If the timing, magnitude, or location of natural disasters were known precisely, the need for insurance would be reduced and the willingness of insurers to assume the risk would vanish. Intentional losses are not insurable. If losses can be predicted, only those who were going to make claims would purchase insurance, and insurance systems would not function.	<ul style="list-style-type: none"> <li>• Statistical and monitoring systems.</li> <li>• Accountability and legal remedies for insurance fraud.</li> </ul>
<b>Mutuality:</b> The insured community must sufficiently share and diversify the risk. The degree of diversification for one insurer is reflected in the number of insurance contracts (or the "book of business" in insurance parlance), geographical spread, etc. The larger the pool, the greater the reduction of loss volatility. Such risks must also be uncorrelated so that large numbers of pool members do not face simultaneous losses.	<ul style="list-style-type: none"> <li>• Create sufficiently large and diversified pools of insureds.</li> </ul>
<b>Adverse Selection:</b> Insurers need to understand the risk profile of the individuals in their market and be able to differentiate the exposures and vulnerabilities of the various customer subgroups. This can form the basis for differentiating premiums or coverage offered. Lack of this information or use of insurance only by the highest-risk constituencies creates elevated risk for insurers, thereby putting upward pressure on pricing and affordability/availability. A key example is the lack of attention to the geographical concentration of risks preceding the 9/11 disaster (Prince 2002) and the ensuing public debate on the insurability of terrorism risks.	<ul style="list-style-type: none"> <li>• Gather market data on vulnerabilities and associated demographic and geographic distribution of risks.</li> <li>• Differentiate premiums among different (risk) classes of insureds.</li> <li>• Rely on government insurance or co-insurance (e.g., U.S. flood insurance program).</li> </ul>
<b>Controllable Moral Hazard:</b> The very presence of insurance can foster increased risk-taking, which can be thought of as "mal-adaptation" to potential changes in weather-related events, which will, in turn, increase losses. This is an issue whether the insurance is provided by a public or private entity. The use of deductibles is the standard method of ensuring that the insured "retains" a portion of the risk. Moreover, the insured must not intentionally cause losses.	<ul style="list-style-type: none"> <li>• Use of fixed deductibles (insured pays a fixed amount of any loss).</li> <li>• Use of proportional deductibles (insured pays a percentage of all losses).</li> <li>• Use of caps on claims paid.</li> <li>• Education and required risk reduction.</li> </ul>
<b>Managable Risks:</b> The pool of potentially insurable properties, localities, etc. can be expanded if there are technical or procedural ways to physically manage risk. <b>Affordability:</b> "Affordability" implies that a market will be made, i.e., that the premiums required will attract buyers. If natural disaster losses or other weather-related losses are too great and/or too uncertain, an upward pressure is placed on prices. The greatest challenge is insuring poor households and rural businesses. This is evidenced by the ~50 % increase in life insurance premiums in Africa in response to the AIDS epidemic (Chordas 2004).	<ul style="list-style-type: none"> <li>• Building codes and enforcement.</li> <li>• Early warning systems.</li> <li>• Disaster preparedness/recovery systems.</li> <li>• Micro-insurance or other schemes to facilitate small insurance for small coverages. Systems must maintain solvency following catastrophic events.</li> <li>• Government subsidy of insurance costs; provision of backstop reinsurance.</li> </ul>
<b>Solvency:</b> For an insurance market to be sustainable (and credible), insurance providers must remain solvent following severe loss events. Natural disasters have caused insolvencies (bankruptcies) among insurers in industrialized countries (Mills et al. 2001), and insurers in emerging markets are even more vulnerable. Solvency has been eroding for other reasons, particularly in the US. (Swiss Re 2002a).	<ul style="list-style-type: none"> <li>• Solvency regulation (e.g., to ensure sufficient capital reserves and conservatism in how they are invested).</li> <li>• Risk pooling; Government insurance.</li> <li>• Insurer rating systems.</li> </ul>
<b>Enforceability:</b> Trust and contractual commitments underpin the successful functioning of insurance markets. Insureds must be confident that claims will be paid, and insurers must receive premium payments. Recent large-scale fraud in the weather derivatives market underscores this issue (McLeod 2003). Many transitional economies, e.g., China, still have insufficiently formed legal systems (Atkinson 2004).	<ul style="list-style-type: none"> <li>• Contract law.</li> <li>• Customer advocates.</li> <li>• Regulatory oversight of insurance operations, pricing, claims processing.</li> </ul>

Source: Mills et al. 2001

APPENDIX D.  
LIST OF PARTICIPANTS ATTENDING THE EXECUTIVE ROUNDTABLE  
SWISS RE CENTRE FOR GLOBAL DIALOGUE  
RÜSCHLIKON, SWITZERLAND  
JUNE 2-4, 2004

**Frank Ackerman**  
Tufts University

**Juan Almeyda**  
Professor  
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**Michael Anthony**  
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Allianz Group

**Adrienne Atwell**  
Senior Product Line Manager  
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**Guillermo Baigorria**  
Meteorologist, Natural Resource Management Division  
International Potato Center (CIP)

**Daniella Ballou-Aares**  
Dalberg Global Development Advisors

**Antonella Bernasconi**  
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**Aaron Bernstein**  
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**Richard Boyd**  
Department for International Development  
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**Peter Bridgewater**  
Secretary General  
Convention on Wetlands

**Urs Brodmann**  
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Infectious and Respiratory Diseases



Natural and Managed Systems



Extreme Weather Events

