# Environmental Quality And Regional Conflict

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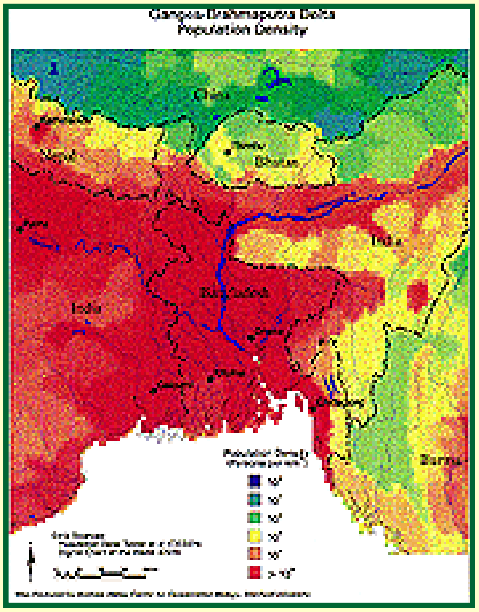
## Acknowledgments

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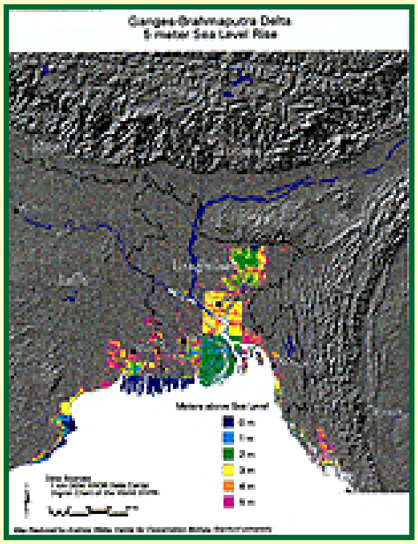
## 1. Introduction



At the request of the Carnegie Commission on Preventing Deadly Conflict, a small group of Stanford researchers began early in 1996 to consider the relationship between environmental quality and the prospect of regional conflict. The group shifted in its composition as the project progressed, but it included environmental biologists, political scientists with interests in security problems and conflict resolution, civil engineers, lawyers, climatologists, and economists.

A central conviction emerged: it was that the environmental sciences have an important contribution to make to understanding conflict liability. Much of the literature on this important subject has been the work of political scientists. Rich and informative though their approach has been, it has generally not employed analyses of likely rates of change in such parameters as climate, ecosystem structure, soil quality, and land cover. We believe that a careful integration of these considerations will improve our chances of detecting "surprises" -- events that might have a profound impact on civil stability, yet are not readily predictable from history.

The group met regularly in various configurations over two years. We settled early on a few guidelines. First, we decided to view the exercise as predictive, not retrospective. Our purpose was to identify regions or nations in which a combination of environmental and sociopolitical (that is, historic, ethnic, religious) factors produced especially high potential for conflict. Rather than add to the already substantial literature of "case studies," in which the sources of past conflicts are analyzed, we saw our task as to bring environmental factors and their rates of change into the picture and use them to identify future problems and designate opportunities for intervention.

Second, we emphasized major forces or trends that might change conflict liability over broad regions and attempted to identify particular geographic regions in which conflict-prone features appeared to be concentrated.

Third, we adopted the potentially risky approach of looking at long-term trends, as well as more proximate kinds of change. Thus the analysis prominently includes, for example, such climate-change ("global warming") parameters as the impact of sea-level change on coastal populations and potential changes in the distribution of disease vectors.

It was our hope in the beginning -- and we knew it was probably too ambitious -- to be able at the end to compare two world maps. One would show the geography of political/social hostility: ethnic enmity, religious and other historical sources of conflict, serious disparities in welfare, and the like -- in short, everything that was *not* environmental. The other would represent regional environmental deterioration: deforestation, contested common-pool resources, soil nutrient depletion, exhaustion of nonrenewable resources, and so on. Superimposing one on the other in a kind of reverse "gap analysis" might illuminate future candidates for conflict hot spots; of course, variations in state capacity to respond to change, whether environmental or political, would also be important.

Not surprisingly, it proved difficult to decide what to map in each case. It was interesting that political scientists experienced in analyzing the causes of "state failure" thought that data on environmental status were much harder to get than data on political, economic, and historical features. The environmental scientists for the most part had just the opposite impression. It turns out that the selection of appropriate indicators, and getting reliable numbers, is about equally difficult on both sides.

Nevertheless, we felt that mapping exercises provided a natural discipline for thinking about the problem, and where it seemed useful we employed this approach even where the data seemed old or less than fully reliable. Although the exercise did not succeed in producing a clear indication of the loci of prospective conflict, we think it did suggest a way of looking at the relationship between environment and conflict that could inform future efforts.

Much of this report is an effort to understand the possible role of environmental deterioration in regional conflict, to project rates at which the environment is being altered by human activity, and to estimate the convergence of these changes with other important variables, like state capacity. We begin with a general discussion of these relationships, emphasizing both the importance of environmental change and that of mediating events -- the political, economic, and social conditions in regions or states that help to determine whether conflict will occur. Next we summarize various vectors of environmental change -- land use, climate, energy demand, agriculture and food demand, water availability, and the status of other common-pool resources. Then we turn to inspect the possible links between these changes and the prospect of violent conflict in particular regions, followed by an examination of some global change patterns that may present more widely distributed problems -- for example, the relationship between climate change and infectious disease. Finally, we try to identify some promising targets for preventive investment.

One cautionary note: our projections often made the world appear to be changing in a linear, even stately fashion. But that may be an illusion. In the end, it is likely that "surprise" occurrences, as much as currently observable trends, will set the environmental conditions under which our successors will live. Only careful scientific analysis will shed light on these possible sources of conflict. At the end of our report we attempt to foresee some possible routes of environmental change that lie outside the "conventional wisdom" about (for example) global warming, land cover change, and water utilization.

## ENVIRONMENT AND CONFLICT: LINKAGES AND MEDIATORS

Before turning to an exploration of possible interactions between environmental change and the propensity for violent conflict, we felt obliged to confront a challenging prior question: Is there really a story here? Does the environment contribute to security problems? More precisely, are adverse changes in environmental quality and resource availability important determinants of whether conflict will occur?

The idea that regional (and, ultimately, international) security is linked to environmental quality is not new. Neither is it uncontroversial. Given the history of migration-induced conflict and disputes over resources between nations, and the involvement of environmental degradation in the mass movement of people, it may seem surprising that there should still be disagreement over the environment-security linkage. But given the complex causal relationships between armed conflict and state failure, and given the strength of alternative explanations, it is perhaps not surprising that some authors committed to the "high politics" of international security regard the issue as merely a way of gaining entry into their domain for a Green agenda.

Differences in outlook may explain, if not resolve, the argument over the relationship of environmental quality with regional security. "Security" can be interpreted in different ways. Used in the sense of "food security," it may mean resource stability sufficient to maintain health and at least a semblance of political order in a population. Or the context could be limited to outright conflict, with the focus on the relationship between environmental quality and violence. Each usage is valid, but confusion about which is meant can lead to unnecessary dispute. We incline toward the latter definition, but we include threats that degrade the values of a nation (or any large population with a community of interests) sufficiently to increase the risk of armed struggle.

Thus we will generally speak of conflict (or susceptibility to it) rather than security. But even that term needs some additional definition. The Commission makes an important distinction between the kinds of issues raised by "led" conflict and the law-and-order problems raised by widespread gang warfare. The two require different solution strategies. But the world is experiencing an increasing volume of diffuse conflict -- violence that, although it involves led groups and is essentially a security issue, is widespread, difficult to isolate, and subject to much local variation. Conflicts of this kind may, in the future, increasingly be the result of environmental factors -- and may present special challenges to preventive strategies.

Another source of disagreement is that some authors have looked through a strong national interest lens, whereas others have focused more on past and prospective conflict in the developing world. We recognize that U.S. policies may be the most available (and possibly the most effective) levers for changing the prospects for conflict elsewhere. Our approach concerns itself with the prospect for local and regional conflicts all over the globe, even where at present those regions appear far from the sphere of U.S. national interest. In our view the time is past when any developed nation can safely ignore large-scale regional instability else where. We foresee a future in which increased population densities and the enhanced potential for rapid communication and for global movement of everything from terrorism to human disease vectors will make all such threats potentially epidemic.

Despite the importance of such threats, as we have noted, the debate has largely been carried on among social (especially political) scientists, with little contribution from the natural sciences.[1] Thus it has been possible for one influential scholar to write: "What we need, if we wish to come to grips with any 'coming anarchy,' is research on conflict, not on the environment."[2] Our view is that we need to know more about both; it is plainly impossible to resolve the debate, which has most often turned on whether "environmental" analyses of past cases have adequately included social and political variables.[3] For purposes of predicting future conflict, we feel free to move beyond the controversy.

Our focus on environmental change requires us to dispense with another chronic disagreement as well -- the long-running battle between, on the one side, many ecologists who see the world as a closed system with increasingly limited resources and, on the other, neoclassical economists who express powerful faith in the capacity of incentives and technological growth to extend those limits. Environmental change and resource depletion are facts of life, but at the same time we know that human societies have a remarkable capacity to adapt. Whether a given situation degrades into conflict will depend on the details: what happens, where it happens, and what kind of societal capacity is available to meet the unexpected.

Moving beyond these two disputes, we need to disclose the limits of what *we* are able to do. Environmental prediction is risky, even though we now have a good grip on the trajectory of some of the changes. Correlation with other variables -- historical, ethnic, and so on -- is more uncertain still. Perhaps most troubling is our lack of knowledge of the likely intervening variables -- the mediators that link environmental change to conflict generation. For example, if environmental deterioration triggers migration, where will the migrants go, and what will condition the likelihood that their arrival will be met with hostility?

Thus the reader who expects a map of prospective hotspots will be disappointed. What we offer instead is an analysis of environmental change, with an effort to couple those changes with other sources of instability. We think it is a method that might suggest routes of preventive intervention, as well as indicate areas in which further knowledge will be needed. Environmental science has an important contribution to make to conflict studies. We live in a time of unprecedented environmental change, and many of these changes are of a kind that might well exacerbate other sources of conflict. Because most of the changes are anthropogenic and because the human population is expected to nearly double in the next half-century, the pace of change is certain to accelerate. In this respect the future is vastly different from the past. It is important to recognize the subtlety, complexity, and possible suddenness of the environmental forces and to identify what kinds of research might be needed to improve our capacity for prediction and conflict prevention. Above all, the character and rate of environmental change urges on us the need for long-range thinking and prognosis.

That will be a major theme of this report, but the social sciences and case studies offer vital guides to understanding the mediating events that transduce environmental degradation or scarcity into deadly conflict. Important lessons can be learned from history and from social theory. Homer-Dixon has developed a general analytical model in which mediating social forces that might link environmental scarcity (a term that embraces environmental degradation, population growth, and resource distribution) to conflict are characterized. These include decreased agricultural production, economic decline, population displacement, and disruption of state and civil institutions. The approach of the Toronto group has emphasized the use of case studies to demonstrate how[4] and where[5] these intermediate factors might operate.

When resource scarcity occurs, perceptions of resource disparity on the part of less-advantaged people result, often followed by the kind of deprivation-induced anger that generates violent conflict.[6] The cases studied by Homer-Dixon and other groups are all of near-contemporary vintage. But there are examples of much earlier human societies in which the connection between resource degradation and conflict may also be seen: these are the societies in which rapid population growth in restricted areas with limited resources may have led to ecological collapse. The social devolution in classic lowland Mayan civilizations and in Angkor Wat followed episodes of overexploitation, though in these cases it is not entirely clear that civil conflict was part of the end-game. On Easter Island, however, the record is clearer. The first Polynesian voyagers arrived on a richly forested island around ad 400. They used the forest to build canoes for fishing and hunting marine mammals, cleared it for agriculture, and cut the trees to make rollers to transport their famous statues. Over time, they achieved a population density of 150 persons per square mile: erosion destroyed the quality of the cropland, all the land-bird species were driven to extinction, and there were no more palm trunks to make canoes. By the time Europeans arrived in 1722, Easter Island had descended into conflict and cannibalism.[7]

LIMITING THE TERMS OF OUR APPROACH

Should we be concerned primarily with international conflict? Linked to the skeptical view of many about the environment's role is a tendency to limit consideration to wars between nation-states.[8] On the contrary, we think it likely that Homer-Dixon is right in predicting that "the violence will usually be subnational, persistent, and diffuse."[9] Certainly the history of war since World War II argues for such a focus. Of the more than a hundred wars that have followed 1945 (defined as violent conflicts with more than 1000 battle deaths per year), over 80 percent have been between nonstate groups, either fighting each other or fighting established states.[10] And of the 30 such conflicts under way now, not one is a pure interstate war -- a point heavily emphasized by the Carnegie Commission in its final report.[11] It is important to note that these two kinds of wars will have quite different kinds of intermediate causes. Nation-states may fight over common-pool resources or perhaps transboundary pollution events, but depletion or degradation may also produce more subtle disparities in welfare that may lead to a kind of conflict that appears to bear little relation to environmental causation. Intrastate (civil) conflict may result from a complex series of events following environmental degradation: worsening of public health, economic collapse, or famine, leading to an erosion of public confidence in the state's capacity to cope, followed by communal violence or civil war.

A second issue emerges as one examines the relationships among "environmental" variables: in particular, whether "environmental quality" should be defined so as to include access to common-pool resources. Although clear distinctions may be made between environmental deterioration and contests over access to shared resources, like water, in practice these often merge. Growing populations experiencing deprivation often migrate in search of improved circumstances, or practice poor conservation methods because they cannot afford better ones. As soils deteriorate, agriculture moves to other, often steeply sloped or forested ground; the resulting change in land cover affects slowly renewed resources -- the soil and its fertility, the quality and availability of the water in whose watershed the land lies, and biological diversity. Even agriculture in fertile lowlands may suffer from resource depletion or flooding. At the same time, urbanization will surely increase competition for increasingly scarce water supplies.

About 65 percent of the people living in what the World Bank classifies as low-income countries are rural; two-thirds of those who are economically active are engaged in agriculture. Nearly all the projected population growth in the world for the next fifty years is expected to occur in these countries, and, despite a rising trend toward urbanization, many of the newly added people will be agrarian and pastoral -- with incomplete connections to markets, depending, as they do now, on gathering a thin livelihood from collecting fodder and fuelwood, caring for animals, fetching water, and growing a few crops. This pattern of life is acutely resource-dependent. On the Indian subcontinent about half the working hours of villagers are spent in these activities.[12] When applied to such settings, the term "environmental quality" has a meaning quite different from the one it takes on in the industrial nations. In the latter, it often means fishable rivers, clean air, and such amenities as national parks. In the developing world it usually means basic ecological economics: loss of environmental quality that forces hungry people to go farther for fuelwood and water, to graze their cattle over a wider area, to grow their crops on more impoverished soils, and to face chronic ill health and poor nutrition. These impacts, if they are severe enough, can lead to mass population movements -- a potential cause of conflict.[13]

Not all contests over common-pool resources are properly within our scope. Valuable mineral resources contained within a particular nation-state often play some role in conflicts over access and control, as with Iraq's invasion of Kuwait in 1989. Such disputes are familiar and treatable through existing, well-understood mechanisms; they are not part of the issue as we have defined it here. On the other hand, transboundary externalities are sometimes produced by the overexploitation of resources or the transport of pollution by the owning nation (for example, acid rain), and such effects are legitimate aspects of environmental security. Other common-pool resources (rivers, aquifers, inland seas, air quality, and -- most inclusively -- global climate) are shared by several nations and may form the basis for what are essentially environmental conflicts. At the local and regional level, institutions of the right kind have often served to sustain common-pool resources and prevent conflict; the literature on village-level management of irrigation districts, fisheries, or grazing lands in various countries supplies abundant examples.[14] Managing such problems on a larger scale is a major challenge in the avoidance of environmentally based conflict.

For practical purposes, environmental quality problems and common-pool resource problems may be indistinguishable. They are likely to become both more pressing and more tightly linked in the future. Global climate change will probably exacerbate some or all of the pressures that are now resulting from population growth and resource depletion. A possible result is that, acting together, the anthropogenic changes affecting environmental quality will increase the probability of mass population movements and of consequent conflict. This linkage was well described by Goldstone, in a thoughtful effort to referee the dispute over whether environment is a legitimate entry in the security arena:

> What our security requires is better research on what kinds of states are likely to experience increased risks of failure due to population and environmental changes, on ways to measure and anticipate the magnitude of such risks, and examinations of the consequences of policy measures designed to reduce those risks.[15]

We recognize the essential character of these connections, and our approach has benefited from past case studies, some of which have been referred to earlier, in which environmental deterioration has been connected to regional conflict.[16] To examine causation requires a convergence of two approaches: one that explores areas of prospective environmental deterioration, and another that looks at ethnic, social, institutional, and political sources of interstate or civil disorder. Equally essential, however, is an understanding of the mediators between environmental change and conflict. How does the one lead to the other? Resource scarcity and human migration have been identified as likely mediators, but how and when these lead to an explosion of violence surely varies with different circumstances. Improved understanding of these linkages is needed, and achieving it has been an important element in the case-study agenda.

We have already emphasized that nations bring vastly different capacities to the challenge of dealing with environmental change. The richer, developed countries have technological, economic, and institutional resources that enable them to deal effectively with various crises that may arise as a consequence of environmental change. Democracies seldom fight with one another, probably because they possess the capacity and resources to negotiate interstate differences.[17] In a valuable recent critique of the environment/conflict relationship, Gleditsch emphasizes that much of the literature overlooks such important differences in state capacity.[18] The differential responses of the United States and Africa to the aids epidemic provide a tragic illustration.

Whether in the form of global warming, soil impoverishment, or epidemic, environmental deterioration is likely to widen the gap between rich and poor states, exacerbating the dissatisfaction of the latter and degrading their capacity to maintain internal civil order and avoid regional conflict. The capacity of international organizations, whether regional or global, to compensate for state failure under such circumstances is important -- and, unfortunately, it is also in doubt. Thus deadly conflict is likely to become, even more than it is now, a problem located in the developing nations. Many of these are postcolonial states that have been able to enjoy neither the sense of legitimacy nor the institutional strength characteristic of the mature industrial democracies of Europe and North America.

This lack of stability and vulnerability to external shocks is emphasized in the Commission's final report. Here we point out that the developing countries are vulnerable in other respects as well. They are nations with burgeoning populations of very young people, and their resources for dealing with dislocations due to a globalizing economy or to environmental problems are limited. Most important, they are the loci of some of the most severe environmental problems, in part because most of them are tropical countries with ecosystems that are especially vulnerable to disturbance. These are the places where state capacity is most needed -- and most often lacking. Homer-Dixon points to the "ingenuity gap" that often prohibits successful responses to resource depletion or ecological disruption.[19]

This combination of features dictates that international prevention strategies be sharply focused on the developing world -- not only because capacity is lacking, but because it is here that rapid and unpredicted changes are most likely to happen. In these circumstances, multiple mediators may link a suddenly altered situation with the prospects for civil unrest and, eventually, violent conflict. However, although projections of environmental change may yield general assessments of what the likely problems are and where they might arise, in the end states may well have to deal with a high level of uncertainty: surprises are likely. The best one can do by way of forearming is to build the research capacity to make better predictions and to have at hand better tools for coping with the unexpected.

We believe that rates of environmental change may be the essential determinants of the future relationship between environmental quality and conflict propensity. The dynamics of global change, predominantly human-induced change, form the backdrop against which other issues -- even the too-familiar argument about whether "environmental security" is a legitimate domain of inquiry -- are to be considered. We begin with a summary of the major variables.

**2. The Changing Environment**

The human domination of the earth's ecosystems is in one sense an extraordinary evolutionary success story. In quite another sense, it poses a potential threat to delicate equilibria that are vital to the earth's natural economy. These include the relationship among fundamental biogeochemical cycles; the forces linking oceans, atmosphere, and climate; and the balance between population and resources.

The extent of that domination has been documented in an impressive summary by Vitousek and his colleagues.[20] Land transformation by human activity -- deforestation, conversion to cropland and pasture, and other modifications -- now involves over 40 percent of the terrestrial globe. Humans now control indirectly, or intercept for their own use, nearly half of all the energy fixed by terrestrial plants in the solar-powered process of photosynthesis. Industrial activity has fundamentally altered the major cycles of carbon, nitrogen, and water. Carbon dioxide added to the atmosphere by fossil fuel combustion and deforestation has increased the concentration of $CO_2$ by about 30 percent above its stable, preindustrial level of 280 ppm/vol. People are now responsible for over half of all global nitrogen fixation. Humans use well over half of the world's usable runoff water, most of it to support agricultural production on the nearly one-quarter of the earth's land surface that is planted in row crops or used for pasture. The impact of human activity on natural ecosystems has been equally profound: about 60 percent of the world's fisheries are overexploited or seriously depleted; nearly a quarter of the earth's bird species have become extinct; and human-abetted biological introduction has radically rearranged the geography of living things.

At the same time, human activity has resulted in the development of a host of technologies that are, at least prospectively, environment-sparing.[21] In the 1950s, world agricultural production was increasing less rapidly than world population; that situation has now been reversed. Our increasing appetite for energy has been accompanied by increasing efficiencies in its use, with the result that in all developed countries energy intensity is decreasing. Of particular importance, because of the connection between carbon dioxide emissions and climate change, is our steadily declining global reliance on the more carbon-intensive energy sources.[22]

These two different and equally correct views of our recent past and our present lead to strikingly contrasting positions about the world's environmental future. The increasingly intense debate between "Malthusian" ecologists and "cornucopian" neoclassical economists will surely complicate the challenging international schedule for reaching agreements about limiting emissions.

In this chapter we consider a number of the potential causes of environmental change, and assess their potential for contributing to conflict.

LAND USE AND LAND COVER CHANGE

One of the primary indicators of environmental quality is how the land is being used. The clearing of forests for agriculture, for timber production, or for rangeland is one of the most evident events of human occupancy -- and one of the earliest, as the drastically altered landscapes of Greece and the Fertile Crescent testify. Yet reasonably current data on deforestation rates are surprisingly soft. Simply to describe land as having forest cover may mean several different things. It could signify "natural" forest, a term that itself may mask a history of significant logging or other human disturbance. On the other hand, it could indicate second-growth or regenerating forest, with species composition quite different from the original, or even a plantation. The difficulty lies in the unreliability of national estimates and the problems in translating satellite images that can readily distinguish cropland from forests but cannot so easily differentiate second-growth from closed primary forest.

Overall estimates of destruction rates for closed tropical forests -- the most valuable sources of biological diversity -- range upward from about 0.5 percent per year, with a best figure of about 0.75 percent per year for the decade of the 1980s. Satellite data and accompanying analysis techniques are improving considerably.[23] Figure 1 maps 1990-1995 average annual rates of deforestation for the world, taken from a Food and Agriculture Organization database.

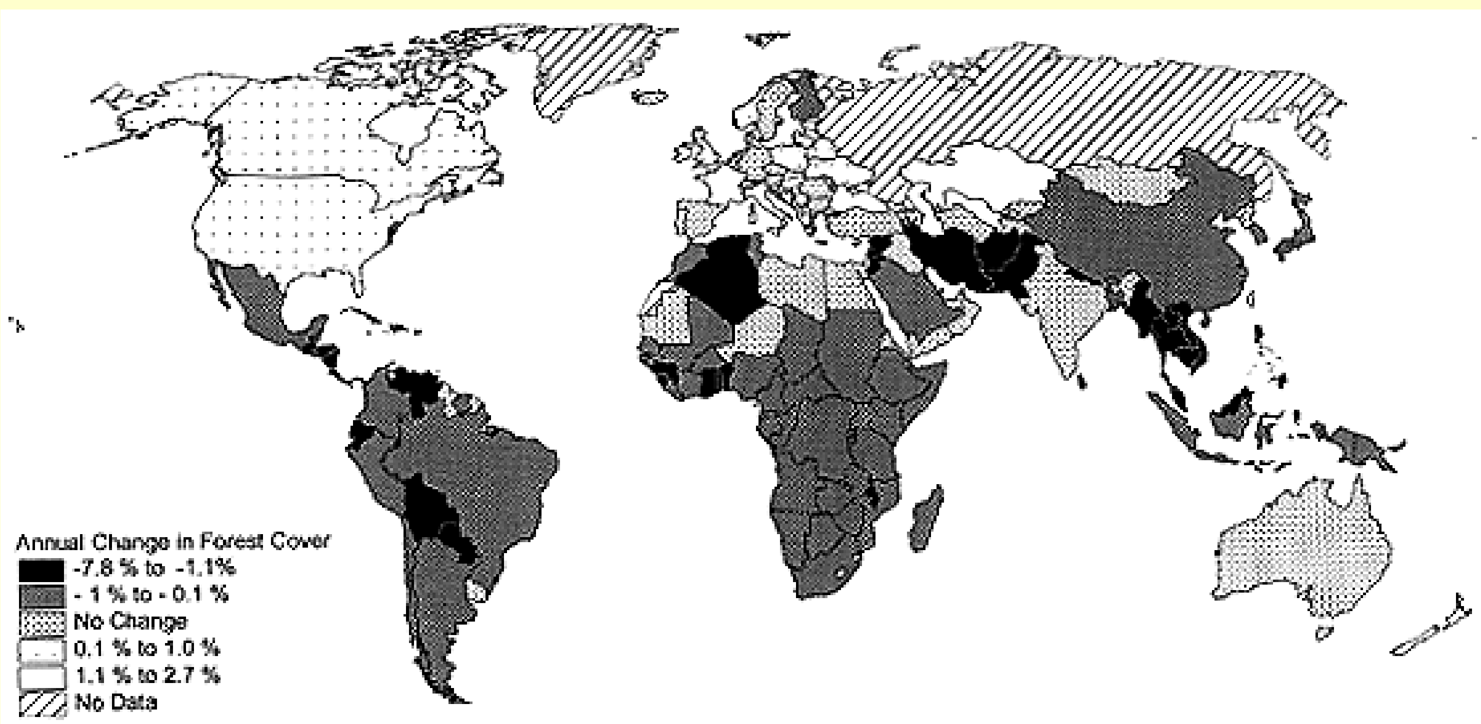


**Figure 1. Annual change in forest cover, worldwide, 1990-1995.** Data from Food and Agriculture Organization, *State of the World's Forests*, 1997. Map from Digital Chart of the World, ESRI, produced by A. Weiss and N. Gove.

Some nations, Haiti for example, are in steady-state with respect to forest loss because they have exploited virtually all available land. Others, like Papua New Guinea, are in the slowly growing early stage. But rates of deforestation in many of the biologically richest low-latitude nations may exceed 1 percent per year. The potential consequences for human populations are significant. Deforestation reduces the retention capacity of watersheds and may produce downstream siltation and flooding far from the actual site of land cover change. Reduction in species diversity may result in the loss of important "ecosystem services," although the nature and value of these is highly location-specific and only beginning to be understood. Clearing closed tropical forests quickly impoverishes the exposed soils, because most of the nutrients are tied up in the living material of the forest and its floor. As a result, cultivators soon need to move to other areas and clear them; the short life of the soil nutrients explains why swidden ("slash and burn") agriculture is commonly practiced by indigenous people in such regions.

How people use the land has powerful, incompletely understood connections with a host of other processes that may affect human welfare. For example, changes in agricultural practice may alter the breeding conditions for an important vector of pathogens responsible for an infectious disease; the introduction of an exotic plant may render an entire region less productive; the management of natural burning cycles may change the composition of vegetation and, indirectly, the availability of surface water. In each case the ultimate consequence results from a chain of events that could not be readily predicted at the beginning. And in each case the outcome could have broad, adverse effects on human vulnerability, trigger massive movements of people, and thus conceivably raise the likelihood of conflict.[24]

The loss of biological diversity associated with deforestation and other human-induced changes in land cover is frequently viewed as a matter interesting chiefly to scientists and nature-lovers, most of whom live in the developed nations. That ignores the vital role that natural ecosystems, with their complex, co-evolved patterns of interdependence, play in maintaining environmental welfare on a regional scale -- a role perhaps even more important in the developing world than elsewhere. Increasingly, it is becoming recognized that the "ecosystem services" provided by natural areas, ranging in scale from tracts of undisturbed forest through wetlands to hedgerows, supply important support for human activities. These values lie beyond those represented by harvestable commodities, and even such non-use values as recreational amenities. Ecosystem services are not traded in markets, but they nevertheless make possible a wide range of human activities. These services include, in addition to carbon storage, pollination of crops, filtration of water supplies, climate regulation, soil fertility, and control of pests in neighboring agricultural areas.[25]

It is clear that deforestation can remove sources of fuelwood and lead to erosion and loss of water quality. If linked to significant migration or coupled with local sources of unrest, the relationship to conflict generation could be quite direct. But the mediating links between collapsing ecosystem services and human conflict are much less clear. This is an area in which it will make sense to prepare for surprises and invest in research that will help to clarify possible developments and their potential for producing abrupt changes in welfare and perhaps migration.

GLOBAL CLIMATE CHANGE

An especially pressing source of concern about environmental change is the prospect of global warming, accompanied by associated disruption of weather patterns. The rate at which continued population growth and accelerating economic activity will add carbon dioxide and other greenhouse gases (methane, oxides of nitrogen, chlorofluorocarbons) to the atmosphere can be projected, but uncertainties about future energy use make the projections subject to considerable error. The general circulation models (GCMs) used to relate changes in carbon dioxide concentration to average global temperature take into account the possible effects of aerosols (which tend to cancel carbon emissions by producing cooling), changes in albedo (as ice melts, the earth may warm faster, because it absorbs more energy instead of reflecting it) and clouds, but uncertainties about the magnitude of these feedbacks have sparked controversy.

Nevertheless, a fairly strong consensus among experts about global warming has developed. It is this: atmospheric carbon dioxide concentration will almost certainly have doubled by the three-quarter mark of the next century. Expert estimates of the impact on average global temperature range between 1 and 3.5 degrees Celsius, producing a rise in mean sea level of between 15 and 90 cm.[26] There may also be secondary changes in weather patterns, including increases in the intensity of violent storms and in the variance of precipitation, but these effects are more controversial.[27] Altered gradients for major rivers could also exert effects far inland.

A growing economic literature attempts to model the consequences of a steady increase in average global temperature of approximately 2-3 degrees Celsius per century.[28] These efforts began with agriculture, but moved on to evaluate the impacts on other economic sectors. Conclusions differ, depending on the assumptions, but the following statements seem fairly safe. Increases in average global temperature could produce significant shifts in agricultural production within the next century: additional carbon dioxide and higher temperatures may enhance production in some temperate-zone croplands while suppressing it at lower latitudes. The magnitude of temperature change is expected to increase with latitude, and evidence from the annual cycle of variation in Northern Hemisphere atmospheric $CO_2$ concentration already suggests a lengthening of high-latitude growing seasons.[29] Not only might high-latitude, technology-rich nations benefit by virtue of location; they are likelier to be able to adapt to change more effectively. Altitude effects are likely to be more complicated, and agriculture at high elevations may have special vulnerability.

Thus steady increases in average global temperature may be expected to have at least two direct but very long-range effects: significant population displacements in sea-level areas, and exacerbation of welfare differences between rich and poor nations. Indirect effects are more difficult to catalogue. The combined impact of altered sea level and enhanced monsoonal forces on coastal populations may be substantial, and a host of secondary responses to changes in precipitation patterns and to ecosystem reorganization are possible.

But the assumption that climate change will be gradual may very well be wrong, providing another illustration that environmental *surprises*, arising from nonlinear relationships among variables, may be the most likely outcome to prepare for. Climate history in the late Pleistocene and Holocene (that is, over the past 150 thousand years) strongly suggests the possibility of more drastic outcomes that might provide more severe challenges to regional or even global stability. The most recent evidence about the history of climate changes has produced two surprising results. The first is that during the cold periods of the late Pleistocene period, the entire earth was colder. It had previously been thought, from analysis of ocean sediments in the climap project,[30] that tropical regions were well isolated from cooling during the last glacial maximum. But ice core data from Greenland, the Antarctic, and the Andes; reconstruction of tropical plant communities by palynologists; and analyses of the past movement of mountain snowlines and glaciers indicate that the colder temperatures were widespread and correlated between the two hemispheres.[31] At the time of the last glacial maximum, centering on 20,000 years ago, the surface temperatures in the tropics probably averaged 5-8 degrees Celsius lower than today.

The second surprise has been the finding that, before about 10,000 years ago, the global climate underwent frequent and relatively brief oscillations between quasi-steady states.[32] These changes, of the order of 6 or even 8 degrees Celsius, took place *over a very few decades* -- much faster than had been previously supposed.

Figure 2 is adapted from the 1996 report of the Intergovernmental Panel on Climate Change.[26] It compares data from the grip Greenland project, a 3 km ice core extracted and analyzed by a group of European scientists, an Antarctic core, and sediments from the North Atlantic. The grip core matches well, for the last 115,000 years, with a core (gisp2) taken nearby by an American team.[33] As the figure shows, the major episodes correlate well with temperature data reconstructed from faunal counts in the North Atlantic sediment cores and with the much more damped shifts in the Antarctic ice record. There is now considerable independent support for these conclusions.[34]

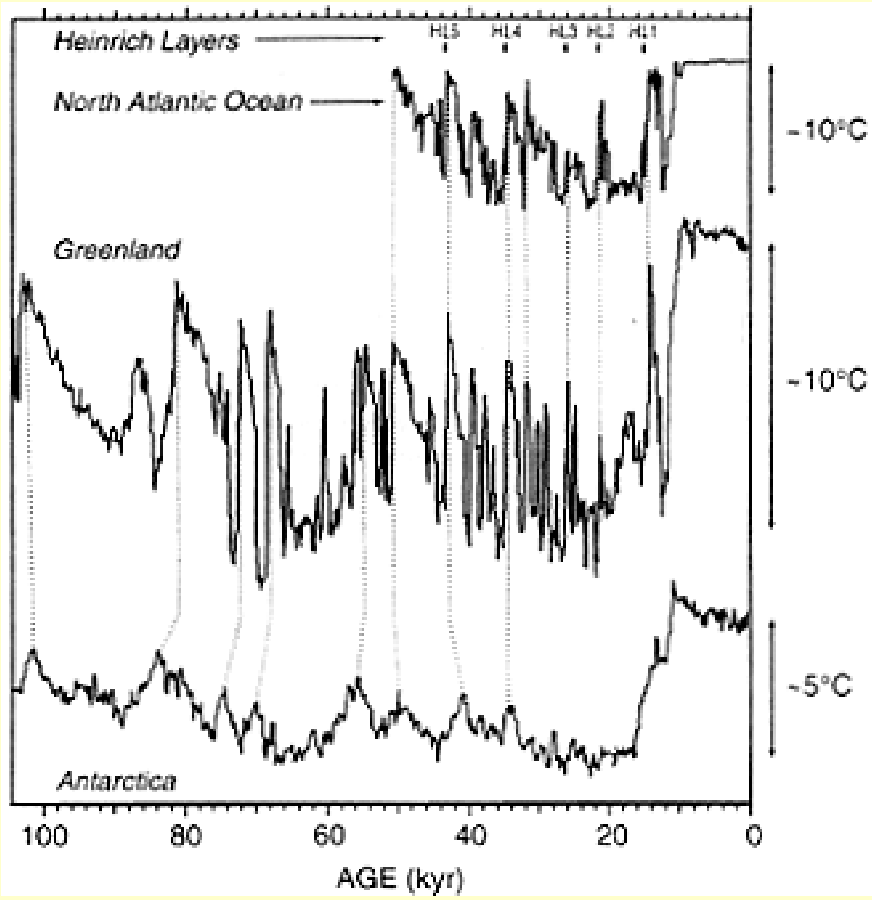



**Figure 2. Records of historic temperature, based on isotopic composition, from the GISP2 ice core ("Greenland"), compared on the same time-scale with an Antarctic record.** In the top two panels, "Heinrich layers" (sediments of ice-rafted terrestrial debris) and temperature variations from the North Atlantic (inferred from the faunal remains) are plotted on the same time scale. The rapid "flickers" in global temperature are correlated in the bottom records, and warming episodes appear to correspond to Heinrich layers, as would be expeted from massive iceberg discharge. Redrawn from Intergovernmental Panel on Climate Change.26

A third independent result, shown in Figure 3, comes from an analysis by Benson *et al.* of dry and wet cycles in the sediments of the Owens Lake basin in California.[35] Oxygen isotope analyses of these sediments match very well with those from gisp2 for four of the last major oscillations during the deglaciation that followed the last glacial maximum 20,000 ybp, including the Younger Dryas. The records also agree with respect to the onset of the Holocene warm period and its relative stability.

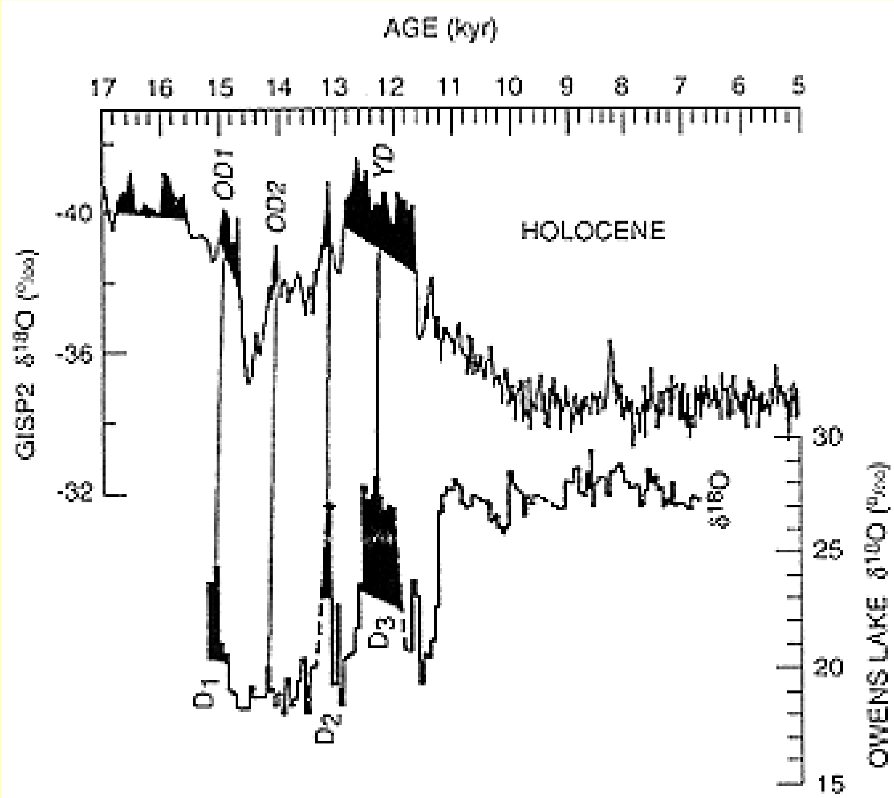



**Figure 3. Record from the GISP2 core (bottom trace), compared with an analysis of the sediments from Owens Lake basin, California.** Both records are based on oxygen isotope analysis; the GISP2 recored is the same as in Figure 2, but only the last 17,000 years are shown and the vertical scale is different. The Owens Lake record shows evidence of wet and dry periods; the latter correspond temporally with periods of cold Greenland temperatures, the last being the Younger Dryas (YD). Redrawn from Benson *et al.*[35]

There is no firm consensus on the cause of the oscillations, nor do we know what later ushered in the warm and stable climate in which the world has been living for ten millennia. The most interesting and plausible explanation for the shifts focuses on changes in the pattern of heat transport between the equator and high latitudes due to alterations in oceanic circulation. Wallace Broeker of the Lamont Geophysical Laboratory at Columbia University emphasizes the role of the "thermohaline conveyor" (thc) in the North Atlantic, which transports surface water warmed at low latitudes poleward. As that water is cooled near Labrador and Greenland, it becomes denser and sinks, providing a return circuit at depth. The working of this heat engine makes the temperatures in Northern Europe several degrees Celsius warmer than they would otherwise be.[36]

If the THC were to be interrupted, it would trigger a massive reorganization of the ocean-atmosphere system. The very top row in Figure 2 is a record of so-called Heinrich layers in North Atlantic sediments.

These are bands of sediment quite different from the usual layers; instead of the compacted skeletons of marine organisms, they contain large grains of material of terrestrial origin that can only have been carried to sea by icebergs that then melted and released their sediment. The Heinrich layers are therefore interpreted as indicating massive discharge from Northern Hemisphere ice sheets. It is hypothesized that such significant increases in the addition of low-density fresh water from glacial melting would dilute the surface water, making it impossible for it to sink -- thereby blocking the thc and ushering in a much colder state. Such injections could equally well come about through a different sequence of events: warming-enhanced evaporation at equatorial latitudes, causing increased cloud formation, followed by enhanced precipitation at high latitudes.

Current policy planning is heavily based on the assumption of gradual warming. But the new data on climate history suggest another possibility: instead, increased forcing will push the ocean-atmosphere system over a threshold of instability and initiate an abrupt change -- most probably to a much colder state. Another prospect for sudden threshold effects is offered by the West Antarctic Ice Sheet, whose collapse could suddenly raise sea levels by 5-6 meters. Recent evidence points to the ice sheet's contemporary instability[37] and strongly suggests that in at least one recent warm interglacial (within the last 1.3 million years) it completely collapsed.[38] Either of these events would pose a serious risk to the coping capacity of the world's society, since highly disruptive events are likely to induce migrations and the collapse of civil order. Yet the possibility of such abrupt events is now being given scant consideration in the global warming debate. Intensified research on paleoclimatology -- especially analysis of the last, even warmer, interglacial, the Eemian (135,000-110,000 ybp) -- as well as on the relations between ocean circulation and atmospheric heat budgets, will be needed to assess this prospect.

A comparison may be helpful here. The social disruption caused by an increase in average global temperature of 5-10 degrees Celsius in a few decades would probably rival that of a major asteroid collision. Significant U.S. government research efforts, as well as lavish attention in the media, have been devoted to the latter possibility. Yet our species has been subjected to at least twenty of the former events during the past hundred millennia, without having experienced a single asteroid accident of substantial magnitude.[39]

## ENERGY AND ECONOMIC GROWTH

Energy extraction and use is the primary engine of economic growth and development. On a global scale the consumption of fossil fuels dominates the picture, supplying 85 percent of the world's commercial energy, with nuclear and hydropower accounting for nearly all the rest.[40] Of the fossil fuel fraction, oil accounts for almost half, with coal and natural gas dividing the other half almost equally. These differences are important because these fuels differ in their "carbon intensity" -- the amount of carbon dioxide they emit per unit of energy produced. Coal delivers most, natural gas least -- and hydropower and nuclear none at all.

Energy utilization rates and their growth are thus of global concern. But it is also significant that within regions, rates of economic growth and energy demand vary widely, with nations having high-growth, successful economies or superior resource endowments often adjoining those with poor populations or impoverished resources. As economic development proceeds, it may accelerate regional demands on scarce resources, and, as per capita income and energy consumption rise, a nation may become a more significant source of transboundary externalities felt by its neighbors (acid rain, air pollution) or all nations (greenhouse gas emissions).

Economic development is a rapidly accelerating, worldwide phenomenon. Welcome as it is, it is also important to examine its relationship to various negative environmental externalities. That relationship has often been expressed in what are generically called "Kuznets curves," after the inverted-U-shaped functions first generated by Nobel laureate Simon Kuznets to describe the relation between income growth and income disparity during industrial development. Various environmental-quality indicators plotted against per capita income yield similar functions, suggesting to some authors that "care for the environment" develops as persons, cities, or nations become more affluent. In fact, the effect probably has two components. One is a technology component, represented by the similarly inverted-U relationship between energy intensity and development. A family of such curves is shown in Figure 4. Energy intensity is expressed as commercial energy units used per dollar of gross domestic product and is reciprocally related to efficiency; it rises as industrial development begins and later falls to much lower levels.[41] There is also a temporal sequence of such national histories: late-developing countries show lower peaks of "inefficiency," suggesting that they have been able to borrow from the technological experiences of the earlier developers. Clearly, increases in efficiency will contribute to the lowering of environmental externalities.

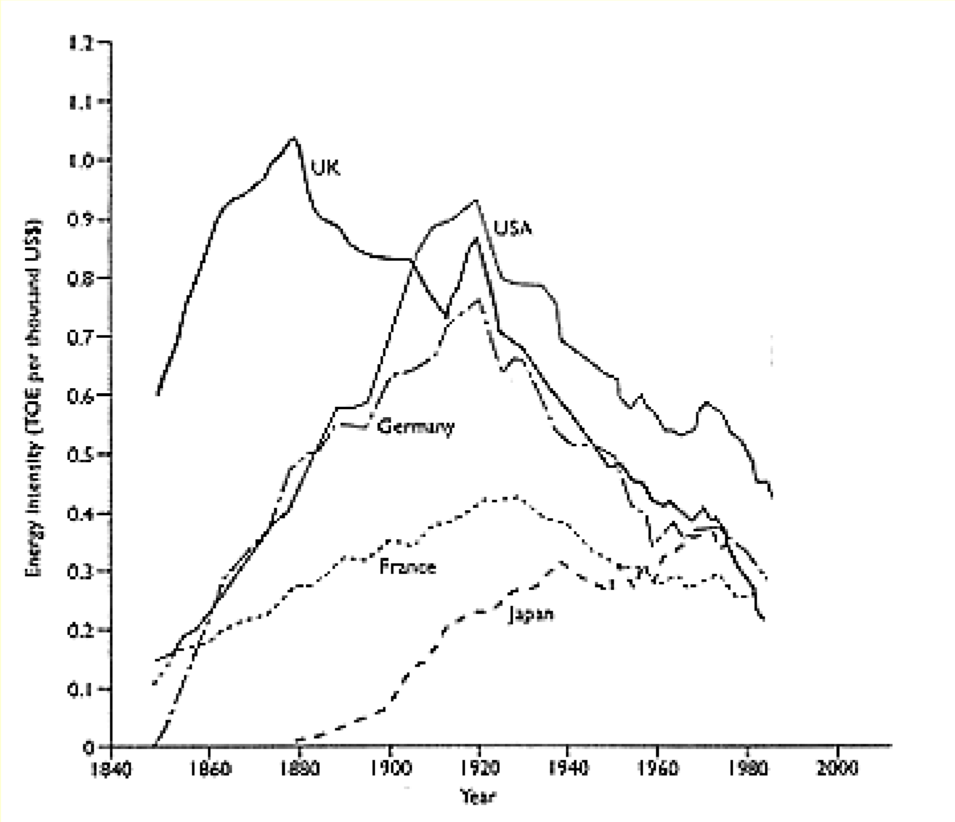


**Figure 4. Changes in energy intensity during the development of several industrialized nations.** Commercial energy use is plotted against time for the United Kingdom, France, the United States, Germany, and Japan. Reprinted with permission from Goldemburg[41]; redrawn from an original paper by Martins, J.M., *Economie et Sociétés* 49:27, 1988.

The second component results from the behavior of individual consumers or groups or from government policies responding to those groups. It seems probable that in addition to the environmentally benign effect of technology-induced efficiency improvements, income has an effect on the choices of individual actors, or communities, or government policymakers. Partitioning the Kuznets relationships between average income and environmental damage into these two components is difficult -- leaving open the question of whether increased income as a general rule leads to increased investments in environmental amelioration. Plainly it has in some of the highest-income Western democracies. But other factors -- form of government, cultural traditions -- doubtless play a role as well. It is thus too optimistic to assume that in China, for example, environmental quality will become a high priority at some particular stage of economic development. This issue becomes especially important, and a potential source of conflict, in situations where neighboring nations differ greatly in affluence, and in which bilateral economic negotiations stumble on environmental issues -- for example, the United States and Mexico in connection with the North American Free Trade Agreement.[42]

Much of the current interest in economic development and energy use is focused on carbon dioxide emissions from fossil fuels and their potential impact on global climate change. Since the drive for economic development will surely continue, global energy consumption will rise, and atmospheric carbon dioxide concentration will continue to increase from its present level of 365 ppm. In the decades before 1970, population growth and increases in per capita energy demand contributed about equally to the rise in global energy consumption and to the increase in carbon dioxide concentration from its preindustrial level of 280 ppm. In the 1970s, per capita consumption slowed markedly -- partly as a result of efficiency improvements in many of the industrial nations (stimulated by the opec oil embargo and subsequent price increases). This effect was probably extended by economic depression in the former Soviet Union and several Eastern European states.

What will happen in the future? World energy demand now consumes 1 percent of proven fossil fuel reserves each year. New extraction and enhanced recovery technologies, and continued exploration, make it unlikely that major shifts in fuel sources will be forced by unavailability in the near to medium term. Thus it seems probable that fossil fuels will continue to dominate global growth in energy use.

Estimating future consumption, in particular its "carbon intensity," presents serious difficulties. Most nations are improving the efficiency of power generation, and there is an important trend in the industrial nations toward "decarbonization." Coupled with the estimated decreases in per capita energy consumption referred to above, these shifts should have produced some effect on the rates of carbon dioxide emission.

The direct records of annual atmospheric concentration changes recorded at Mauna Loa (Figure 5) show striking annual variations due to seasonal changes in the balance between photosynthesis and respiration in Northern Hemisphere vegetation, indicating that emissions can influence atmospheric concentration with very short delay. There is a subtle secular change in the Mauna Loa record, not visible in the figure, which may represent recent declines in per capita energy utilization. Interpretation is difficult: the "anomaly," which begins around 1982 rather than a decade earlier, suggests that significant changes in the biological "sinks" for carbon storage (acceleration of photosynthetic carbon fixation by increased temperature or $CO_2$ concentration) may obscure or otherwise complicate changes due to differences in industrial carbon release.[43]

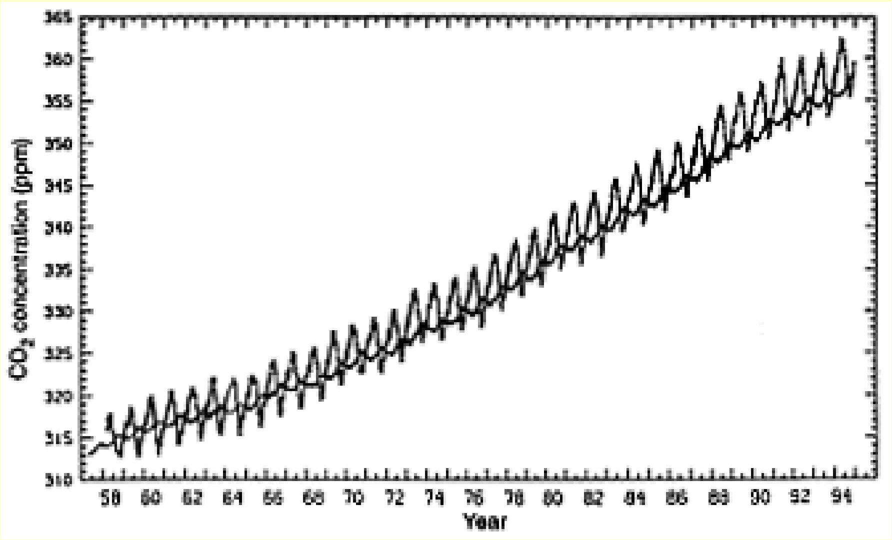



**Figure 5. Time trend in the concentration of atmospheric $CO_2$ (ppm by volume) at Mauna Loa Observatory (cyclical) and at the South Pole (more damped record).** Reprinted with permission from Keeling *et al.*[29]

All this is perplexing for policymakers, who must choose how to project future emissions. Should we continue to project atmospheric accumulation of $CO_2$ by aggregating national estimates of economic growth, efficiency improvement, and decarbonization? Or should we, as has been suggested in jest, simply linearize the directly measured data on atmospheric $CO_2$ concentration, and extend the line -- thus assuming that history is the most reliable guide to what will happen in the future?

The difficulty of making estimates of changes in per capita energy demand and its impact on emissions is apparent at the local level, and that also adds to the problem of ensuring compliance with international agreements to limit emissions. In developing nations particularly, the addition of electric power-generating facilities may increase per capita energy consumption and add a major new source of carbon emissions -- especially if the new facilities are coal-fired. But if the result of electrification is to convert small process industries from internal-combustion drying and to supply electricity to rural households that were cooking and heating with coal, the net consequence would be significant reductions in per capita carbon emissions. Accurate projection (not to mention the regulatory system needed to secure compliance with national emissions caps) would thus depend on data at the level of households and small firms, and these are not available at this time.

The disjunctions between existing macro-estimates of energy demand and use, on the one hand, and the direct data on carbon dioxide accumulation underscore the difficulty of making projections in this area. National data, even on present economic growth and energy demand, are subject both to bureaucratic optimism and inflated political claims. In the preparations for the December 1997 Conference of the Parties to the United Nations Framework Convention on Climate Change in Kyoto, many nations offered emissions reduction targets that were plainly impossible to achieve. European claims for past reductions, based on consumption rather than emissions data, are equally suspect.

There is also a frequent failure to connect central directives to on-the-ground implementation. China, for example, reports rates of economic growth in the 9-10 percent range -- but the figures for growth in energy demand are much lower, of the order of 6 percent. Is energy efficiency really improving at 3-4 percent per year? We do not know, but there are several reasons for skepticism. First, the data may not be reliable. Even if they are, much of the apparent improvement may be due to disproportionate growth in such non-energy-intense sectors as services, which inflates the gnp denominator.

To summarize: as a policy planning tool for making projections about climate change, we would like to have accurate data on, for example, current emissions and rates of past change in demand. The disparity between aggregated "bottom-up" estimates of this kind and the record of global emissions suggests considerable doubt about the reliability of the former, making it difficult to project the per capita component of emissions growth. Should one assume that efficiency improvements and decarbonization (through shifting from coal to less-carbon-intensive sources) can reduce the per capita increase that would be expected from economic growth, and, if so, by what fraction? Should it be half, as is apparently claimed for China? Or will there be, as the past global emissions picture suggests, an unexpectedly weak coupling between these aggregated macro-data and the final common path of atmospheric carbon loading? Here is a place at which the environmental pessimists and the optimists may have to declare a tie, or perhaps a forfeit, and move on.

These are important matters, for rates of energy use and changes in those rates are essential for predicting the climate future. Although this is a variable likely to act at fairly long time scales, no parameter of environmental change offers a greater opportunity for generating instability, mass movements of people, and potential conflict. To make reasonable predictions in this area will require more knowledge of the ways in which economic development affects energy use, especially carbon intensity. Such research is needed if we hope to refine the accuracy of climate-change prediction, as well as to envision vital future resource shortages that might, in and of themselves, raise the prospect of interstate conflict.

## SOILS AND AGRICULTURE

On a global basis, agriculture is a great success story. Despite dire predictions in the 1960s, world food production has more than kept pace with population growth in the three subsequent decades, and real-world prices for the major staple commodities have dropped substantially. At a more local scale, however, the story is much more mixed: the global figures mask serious problems with access to food, problems that have led to crises, generating migration and episodes of starvation.

That should be no surprise: arable land is not equitably distributed around the world, especially in per capita terms. Figure 6 displays that distribution, which correlates only weakly with the geography of nutritional well-being. Some nations with small amounts of land per person manage to feed their populations very well (for example, Japan and the United Kingdom); others with a relative abundance fare poorly (among them, Afghanistan and many nations in sub-Sahelian Africa). This underscores the importance of income in determining nutritional status.

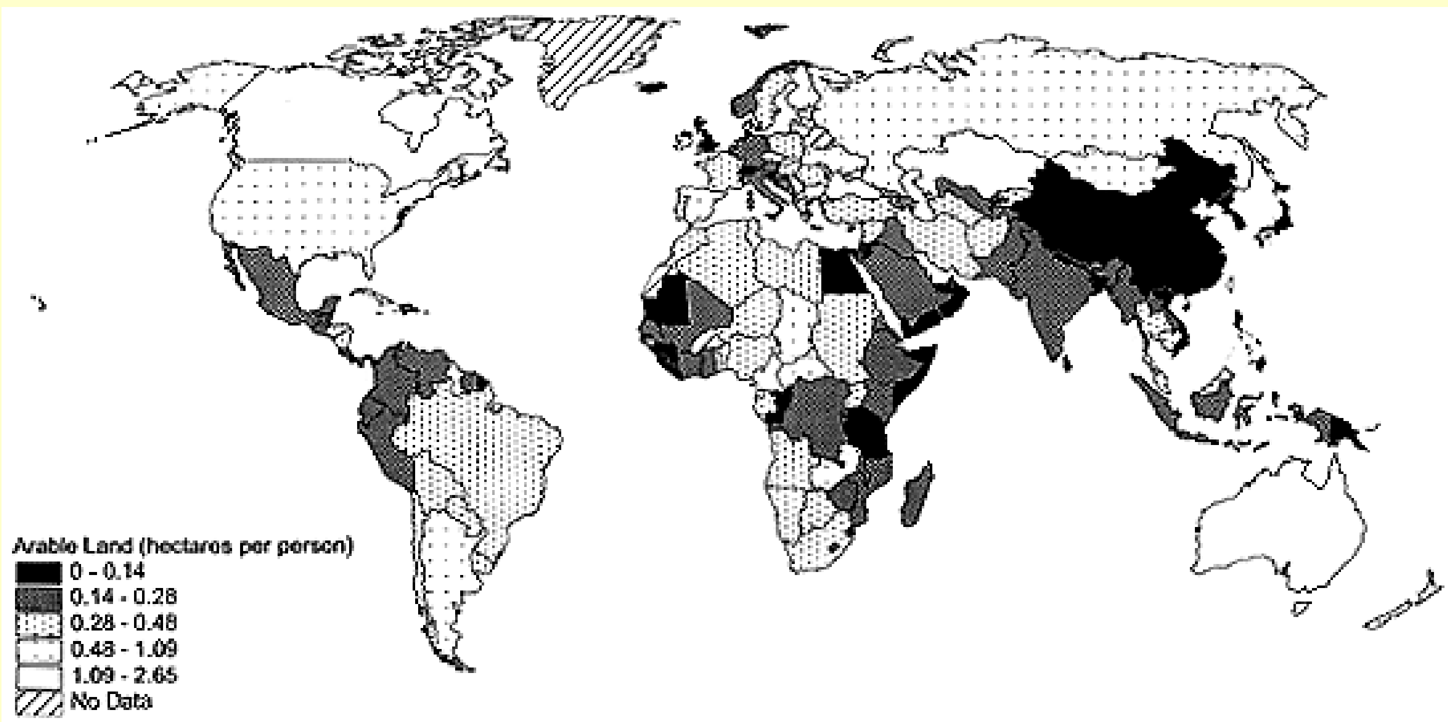



**Figure 6. Arable land, in hectares per person, 1994.** Data from World Bank, ESRI map produced by N. Gove.

The geographic deployment of "arable" land, furthermore, is not the whole story. Repeated use of initially good land for agricultural purposes may deplete the soil of nutrients; tillage exposes soils and makes them potentially more vulnerable to erosion by wind and water. Regular fertilization, even though it may restore the nutrients, can result in degrading the soil by depositing salts. Irrigation, in addition to exacting costs on water (see page 30, below), often accelerates nutrient loss and accentuates salinity problems.

There is general agreement that significant gains in food supply -- essential if we are to meet the food needs of a growing human population with increasingly calorie-intensive diets -- must be achieved primarily through increases in yields rather than acreage. Most of the land suitable for agricultural production is already used for growing crops. Any "unused" land that remains is mostly marginal for agriculture. Furthermore, it may well be more valuable for other purposes -- conserving biological diversity or supplying other ecosystem services, for example -- and it may also be especially vulnerable to environmental degradation if cropped.

This opens three questions. First, are agricultural science, technology, and local application equal to the task of generating yield improvements to meet a world demand for food that may double, or more? Second, is soil quality around the world good enough to sustain present levels of intensity, let alone the much higher ones that will be required? Third, what effect will global climate change have on agriculture around the world?

On each question there are differences of view. Some observers[44] believe that erosion is now a major threat to agricultural sustainability, whereas others challenge the numbers. Even the challengers, however, cite estimates of annualized productivity loss in the vicinity of half a percent per year.[45] The difficulty is that regions differ greatly in vulnerability, soil quality, and precipitation regimes. Most national and global estimates have been obtained by multiplying one or a few regional measurements by total acreage. Erosion losses are also often not net losses: windblown soils may land elsewhere, and much soil lost to water erosion contributes to a fertile floodplain downstream.[46] Acidification by human agency is also a problem for soils in many parts of the world. In the northeastern United States, sulfur dioxide emissions from Midwestern power-generating facilities and industrial plants have produced problems for forest soils and for agriculture. Long-term studies indicate that chronic acidification leaches calcium and other divalent cations from the soil and reduces its capacity to deal with further acidification; these long-term effects have counteracted efforts to deal with the problem through the "tradable permits" provisions of the 1990 Clean Air Act Amendments that were supposed to reduce sulfur emissions.[47] In China the problem may be more serious, and is likely to get worse as coal-based energy development proceeds (see page 45, below).

Even if soil quality were to remain at present levels indefinitely, it is not clear that the needed intensification can be accomplished. Smil[48] has examined the potential sources for such improvement, and estimates that various efficiency gains -- agronomic practices, water management, reduced waste -- along with dietary changes could accomplish gains of about 60 percent. He accepts the "worrisome changes" represented by exhaustion of nonrenewable water supplies, soil erosion, salinization, and loss of biodiversity,[49] but asserts that these can be reversed by rational agronomic practices.[50]

There is a more optimistic view, expressed by Waggoner.[51] He points out that "if we stopped feeding crops to animals, became vegetarians, and replaced coffee beans with garbanzo beans, the croplands would produce 2900 consumable calories" per day for the expected 10 billion people at midcentury. Recognizing that people will in fact *not* do those things, and that diets are shifting in the direction of animal protein, he nonetheless concludes that a more "American" diet for the 10 billion could be accomplished while sparing land for nature.

These estimates, however, are based on yield improvements accomplished by temperate-zone farmers, on the best land. The achievement Waggoner predicts is certainly conceivable, but it depends on an extraordinary convergence of "best-case" outcomes for a variety of input technologies. It also relies on the sustainability of soil and soil nutrients, water for irrigation, and genetic resources, and assumes no negative externalities from inputs like fertilizer and pesticides. Like many top-down assessments, it suffers from overaggregation -- passing over regional or local problems of availability, and ignoring entirely the demand-side issues related to prices and purchasing power.

Genetic resources are sometimes ignored as inputs to agricultural production; yet of course genetic manipulation (along with intensified use of irrigation and the chemical inputs new varieties often require) has been responsible for most of the gains in production that have kept food supply ahead of population growth for the past forty years. Continued progress will depend on maintaining or increasing the pace of genetic research, on the effective conservation of germplasm resources (including both the products of variety development by geneticists and farmers and the wild relatives that serve as sources for new material) and on the acceptability of innovations at the farm level.

The sustainability of the research effort is under some threat from the reduction in real funding of the centers of the Consultative Group on International Agricultural Research (cgiar) that have been the source of so much past progress. Conservation of genetic resources suffers from reductions in a number of important national "gene banks" and from the potential loss of wild relatives through destruction or fragmentation of natural ecosystems. But perhaps the most troubling threat is the unexpected hostility of international and many developing-country nongovernmental organizations to the use of biotechnology (that is, the use of recombinant dna techniques to create new kinds of crop plants, or organisms useful in the biological control of pests). These new technologies offer much hope for intensification of agricultural productivity, and a number of distinguished scientific panels in the United States and Europe have concluded that the methods used in constructing genetic novelties do not, in and of themselves, introduce additional risks. Rising opposition in the European Union and in a number of developing nations may preclude the deployment of valuable methods in the cause of improving agricultural production.[52]

The importance of biotechnology and other genetic methods to the future of world agriculture and to food security is difficult to overstate. Increasing the tolerance of crop plants to biotic and environmental stresses should enhance food security by reducing variability in yield. The evidence suggests, however, that in some cases genetic manipulation may actually increase the dependence of yield on such major climate variables as rainfall and temperature. Plants pressed to maximum yields put dependent populations at increased risk for two reasons: production, pressed to the maximum, has farther to fall in a bad year; and emphasis on yield alone may have reduced the crop's capacity to deal with increased environmental variability. Given the likelihood of future climate change, research efforts should focus on yield improvement in the presence of greater variation in water availability, temperature, and other factors.

The emerging privatization of genetic resources may raise problems for developing-country agriculture. Although several issues concerning intellectual property rights issues are still unclear, more and more plant breeding and research is being conducted in the proprietary sector -- a sector characterized by increasing concentration and mergers involving seed companies, chemical firms, and biotechnology companies. Perhaps a parallel with the pharmaceutical industry, where market size often determines technology development, is emerging. In the agricultural sector, the equivalent of "orphan disease" (a condition that, although serious, affects a relatively small number of sufferers) may be "orphan crop" (a commodity important only regionally or locally) or "orphan region" (where poorer nations dependent on particular crops, particular climate and soil types, and institutions for distributing inputs fail to offer enough prospective return on investments by industry).

Agricultural failures promise a whole array of adverse consequences for regional populations. Nutritionally deprived, weakened populations may be less conflict-prone for that reason; but prospective or developing starvation (caused by resource depletion and population growth) has been a source of mass movements and subsequent conflict.[53] Failure to produce adequate yields often results in expansion of croplands to other areas, accelerating other forms of environmental deterioration such as forest clearing -- a pattern possibly involved in the ecological collapse of early lowland Mayan societies.

WATER

When environmental change affects the supply of vital resources that are shared by peoples and nations, it changes relationships and offers new opportunities for disputes. In the realm of common-pool resources, fresh water occupies a vital position. Not only must there be enough water; it must be of acceptable quality, or it cannot be utilized for agricultural, domestic, or industrial purposes. And there is a relationship between quantity and quality: when water is scarce, salt, toxic solutes, and microbial contaminants become more concentrated and deplete its usefulness.

Water utilization in the global context is changing rapidly. Available water for agricultural, industrial and household use is limited; human appropriation of the accessible renewable supply of fresh water is approximately 30 percent.[54] As populations grow, appropriations are increased by damming rivers, pumping groundwater, and recovery of recycled water by downstream consumers. These gains may be offset in the longer run, however, by siltation behind dams, increased evaporation losses, and overdrafts from slowly renewable underground aquifers. Dam construction worldwide has slowed greatly, and water use for irrigation -- the source of most human withdrawals -- has reached a virtual plateau as the world's irrigated acreage has stabilized.[55] Utilization of "fossil" (slowly renewable) underground water supplies often exceeds recharge rates, and many nations and regions, particularly in the developing world, lack the groundwater management and drainage plans needed to prevent the deterioration of water quality and overdrafting by individual consumers. Thus depletion of supplies critical for agriculture already is a serious prospect in some localities.

Whether available water supplies will, on a global basis, be able to keep up with growing human demand depends on many factors. Some have to do with environmental factors not yet fully understood: siltation rates, climate changes, and rates of pollution. Others, perhaps the majority, have to do with human innovative capacity: On the supply side, can we find and develop new sources? And on the demand side, can we develop water-sparing technologies for use in agriculture, industry, and households that significantly reduce per capita withdrawal? Still others lie in the domain of political economy. Water utilization, even more than other areas of resource management, is afflicted by deliberate underpricing, differential subsidies by end-use, and irrational incentives. Clarifying rules and getting prices right will play a determining role in the future of water availability.

Water is often a transboundary resource. More than two hundred rivers, and many underground aquifers, are shared by more than one country. Internationally as well as locally, diversion can be a source of tension among prospective users -- although informal local arrangements that allocate water are often ingenious and stable.[56] In this respect the problems that arise out of changes in water availability resemble those that arise because one nation or one group utilizes a common-pool resource to the detriment of other users. Problems of this kind have sometimes led to conflicts between nations that share underground aquifers or rivers, but historically "water wars" have been relatively rare -- perhaps because desperate shortages sometimes stimulate cooperative solutions. Water shortages can be expected to increase dramatically, however, as developing-nation population growth and urbanization place new demands not only on quantity but on quality as well. The possibility that large-scale future population displacements will be triggered in this way cannot be neglected as a potential source of conflict.

OTHER "COMMON-POOL" RESOURCES

The quality of the air or of shared water resources, whether marine or fresh, is analogous in some ways to the availability of water supplies. Whether nation A deprives downstream nation B of water in a shared river or leaks a pollutant into it, the impact is similar: both are appropriations of a common resource that is "rivalrous" (that is, its use by one reduces its availability to others) and "nonexcludable" (property rights or other means are not available to exclude other users).[57]

It is not possible to identify clear global changes in the levels of the conventional forms of pollution. Air quality in the developed world, like water quality, is certainly improving; in many developing regions and nations, it is static or getting worse. As industrial development proceeds in the developing world, transboundary pollution problems are almost certain to worsen. For example, energy development in China is likely to create acid rain problems not only within China but on the Korean peninsula and in Japan as well. Increasing dumping of waste in semi-enclosed seas has increased over the past several decades, and provides a potential source of conflict in areas like the Sea of Japan.

The disastrous decline in the world's marine fisheries has been analyzed extensively. It has been a lively source of mostly ritualized conflict involving the fishing fleets (and sometimes the navies) of developed nations like Spain and Canada.[58] Assigning property rights to open-ocean fisheries, especially for migratory species, is a problem that has proven to be almost intractable; the result has been a series of conflicting national claims and, in some cases, treaties. The collapse of fisheries is a problem as complex as it is daunting. Some of the difficulty is scientific: resource managers have had difficulty selecting ecologically stable levels of harvest. Some of it is in the domain of policy: regulation by controlling fishing effort has often merely provided incentives for improved efficiency, thus negating the purpose of the regulation. There is a rich literature describing the problems of international fisheries management and defining some of the research needs.[59]

### 3. Environmental Change and the Possible Links to Conflict

Having outlined some of the areas in which human-induced environmental change is both rapid and threatening, we now turn to an examination of the potential for environmental change to exacerbate the prospects for conflict. Without some sense of what changes in the environment are occurring, and what changes may be in store for us, we clearly cannot make sensible guesses about where future environments may conduce to the kind of desperation that leads to fighting.[60]

The task of measuring and anticipating conflict liability suggests one possible approach. One might estimate the potential magnitude and direction of environmental change, locating zones of critical resource depletion, and then evaluate how these might interact with various human factors -- population growth, welfare and equity, historical animosities, and political institutions. The objective is to uncover possible mediators and then determine where they might act.

HUMAN FACTORS

We begin with the non-environmental parameters. One approach has been to look for fracture-lines -- zones of historical conflict between states or ethnic groups, or, in Huntington's controversial formulation, the boundaries between civilizations.[61] Another, emphasized by Gurr, identifies the importance of transitions of power, particularly where states are weak and heterogeneous.[62] Regions in which major powers lack controlling influence would be especially likely zones for probing and testing.[63] These approaches are aimed at predicting where local flare-ups as well as traditional interstate conflicts might arise. The Transcaucasus, with its Christian-Moslem divide, its history of ethnic tension, and its rich and often-contested resources would stand out on such a map. The Fergana Valley in Central Asia, an important and environmentally sensitive area for agricultural production, is ethnically intermixed and potentially explosive. Other "non-environmental" factors that might be identified include zones of sharp difference in population density per unit of usable land area or in individual welfare -- gradients that might make state boundaries especially combustible. The zones of separation between Europe and North Africa and between the United States and Mexico are examples.

A number of studies have examined such sources of conflict, and many of these are cited in the Commission's final report.[11] The most exhaustive and recent has been the State Failure Project (SFP), a comprehensive effort sponsored by the Central Intelligence Agency and engaging a wide range of academic and government scholars. This exercise provided an exhaustive index of the factors that may have been involved in 115 incidences of "state failure" between 1945 and 1990. Failures were defined in terms of collapse of governing institutions and outbreaks of serious conflict; for each failed state, three "control" states, comparable in other features but not failing, were identified for comparison. Some 300 potential factors were then evaluated; most were thrown out because the data were inadequate or comparisons were not possible. The 75 factors that remained were compared in failed and control states for two years before and two years after the failure incident.

The SFP results provide a promising source for seeking correspondence with environmental quality data. In brief, the findings from this extensive exercise isolated three sets of factors that were predictive of state failure. Among these, infant mortality, which is likely a proxy for a host of welfare indicators, was especially important. Figure 7 shows the geography of that variable. In democratic countries, risk of failure was greater when infant mortality was high. Involvement in international trade was also meaningful, leading to greater stability both in democratic and less democratic countries. The SFP analysis also confirmed that youthful societies experienced increased failure risk (see below). Especially high-risk situations involved states in which a ruling elite represented only one group in a society that was divided ethnically or religiously.

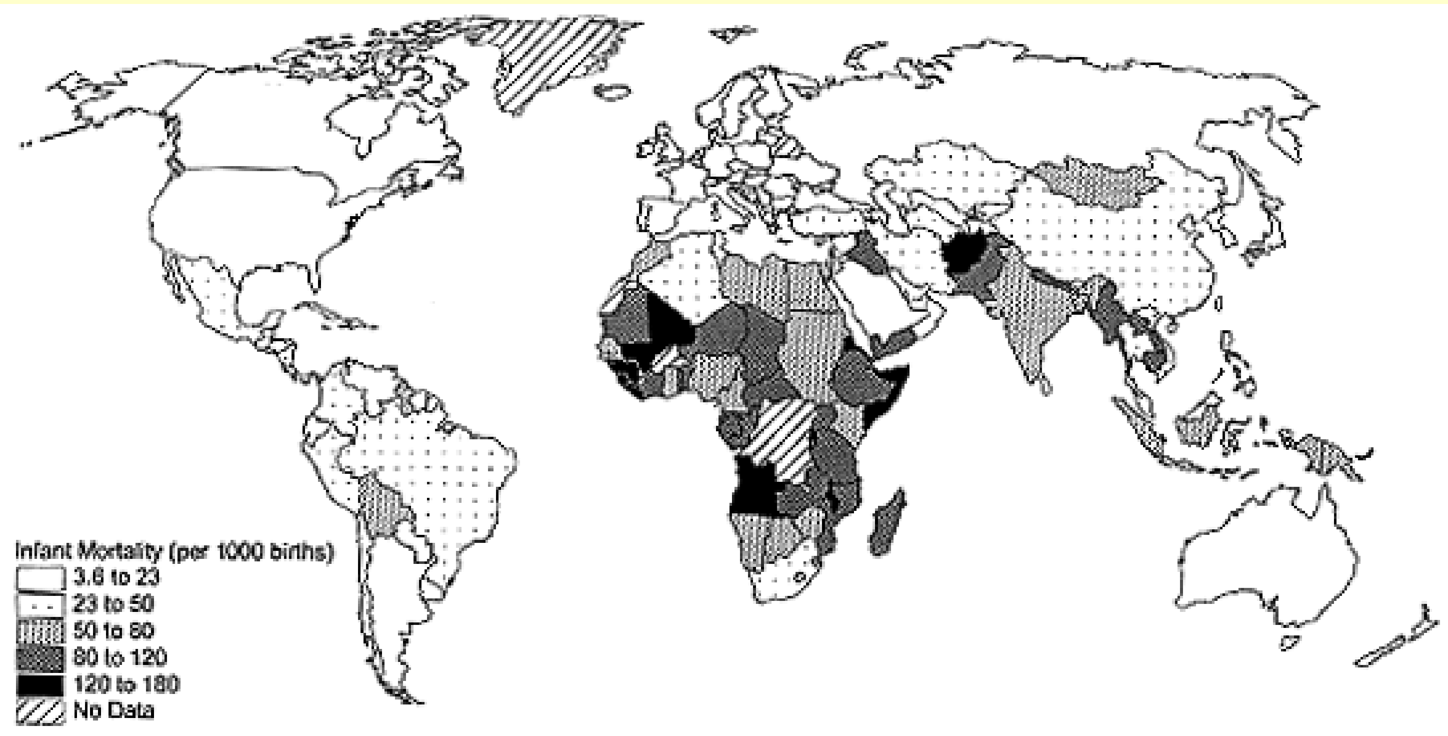



**Figure 7. Infant mortality (deaths per 1000 births), 1995.** Data from World Bank, ESRI map produced by A. Weiss and N. Gove.

Various other indicators that have been used as possible indices of stability: the Freedom House annual *Freedom in the World* and the United Nations Development Programme's annual *Human Development Report,* among others. We considered combining several of these indicators to see whether a normalized composite map suggested anything about conflict liability, but they seemed to us less useful than the State Failure synthesis. The U.S. Delegation to the United Nations also produces a summary of Global Humanitarian Emergencies, which gives an indication of present stress due to conflict and/or repression. An effort to combine some of these indicators with certain environmental variables, like water scarcity and food dependency, has been undertaken by Lonergan under the auspices of the Canadian Global

Change Program.[64] A daylong meeting with a number of social scientists at Stanford[65] identified a number of countries -- for example, Indonesia, the Koreas, Iraq, Pakistan, Afghanistan, Turkey, and China -- as conflict-prone, in addition to those labeled by the infant mortality indicator or the various combinations of factors employed by others.

Perhaps the most important of the "human factors" is the growth of the human population. It is fundamental to many of the environmental parameters, especially in the developing world, where most future population growth is projected to occur. Although the 1996 revisions of the United Nations fertility rate estimates offer some encouragement that the rate of growth may be declining, un and World Bank median estimates still place world population in 2050 at approximately ten billion. More than 85 percent of the world's population will then live in the developing world, and more than 80 percent in cities.

Population growth may affect security for reasons unrelated to environmental stress or resource shortage.[66] The poorest and fastest-growing countries are characterized by bottom-heavy population profiles: they are nations of young people, the ones that yield the sad images of barefoot children with automatic rifles. Their political instability may be in part a result of their demographic structure; and in their relations with other states they seem likely to confirm the prophecy that "teen-age populations are unlikely to be easy to negotiate with."[67] Figure 8 maps the distribution of nations according to the proportion of their populations that are age 14 and under, indicating the size of the "youth bulge." The distribution demonstrates the strong negative correlation between the youthfulness of a population and income; compare Figure 8 with Figure 9, which displays gnp per capita.

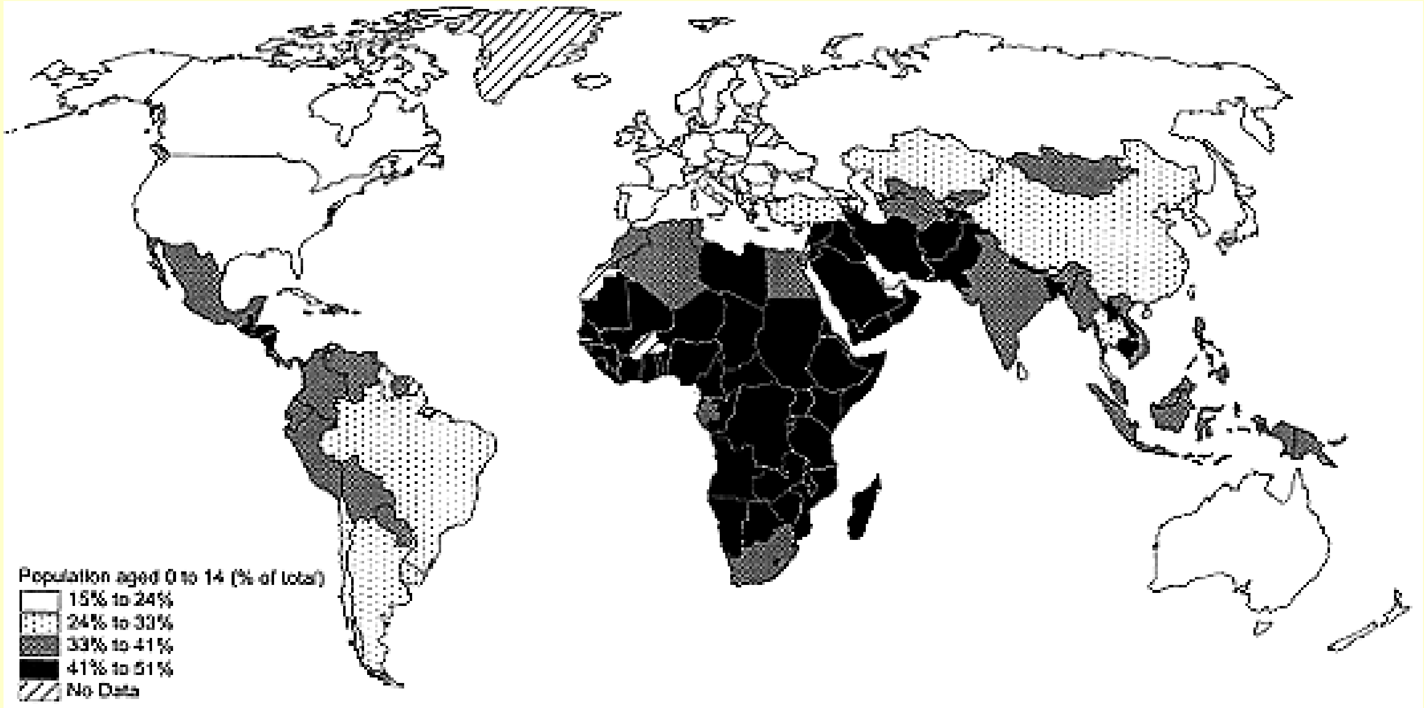


**Figure 8. Map of the "youth bulge" showing proportions of the populations in each nation that occupy the 1-14-year age interval, 1995.** Data from World Bank, ESRI map produced by A Weiss and N. Gove.


**Figure 9. World distribution of gross national product per capita.** Data from World Bank, ESRI map produced by N. Gove. All data are for 1995 except as follows: Cyprus 1994, Iran 1992, Puerto Rico 1993, Sudan 1992, Somalia 1990. Except for Iran and Cyprus, the categories are unlikely to have changed for 1995.

The concentration of population growth in the poor nations and the collateral effects of urbanization are dramatic changes that underscore the need for projecting food needs, energy requirements, and potential loci of mass population movements. Urbanization has historically produced a sequence of dietary changes (from root crops and low-grade grains to high-grade grains and meat) that appears to characterize some present urban transitions but may not be a feature of all. The outcome will determine how much agricultural intensification will have to occur against a cropland base that is unlikely to be expanded and may even contract due to depletion. Per capita energy and water requirements similarly depend on assumptions about economic growth and dietary choice.

Where large or rapidly growing poor populations are near regions that offer attractive opportunities, significant in-migration (possibly accompanied by exploitation) is likely. For example in East Asia, a ring of economically successful, rapidly urbanizing states and regions relatively near the coast (for example, Singapore, South Korea, Taiwan, and the urban East of China, including Hong Kong) surrounds an immense core of rural poor. Migration is already extensive within China, from the interior to coastal provinces like Guandong and cities like Shanghai, and large and growing income differentials are likely to accelerate it.[68] Even larger inequalities exist in some Latin American nations, especially Brazil -- and within South Africa and between South Africa and neighboring states, where they are amplified by racial hostility.

It seems likely that in some cases, the economically vigorous nation will become a magnet for immigration from poorer neighbors.[69] The relationship of Turkey and other states in the Middle East and North Africa to Europe may portend this kind of difficulty. A study of the past relationship between Bangladesh and neighboring regions of India suggests that heavy migration (leaving, according to estimates, 15 million Bangladeshi migrants and their descendants in Assam and other nearby provinces) has added to historic ethnic and religious tensions and has triggered repeated civil violence.[70]

Special attention should also be given to differences in income distribution. States with modest disparities may be attractive to the poor in neighboring states with large disparities. Strong regional income differences *within* a country may produce intrastate conflict if it goes unaddressed. Wise rural-environment policies (particularly with respect to the agricultural sector) can encourage growth without promoting income disparity, and encouraging these may reduce the potential for conflict.

ENVIRONMENTAL PARAMETERS

Environmental change and its impacts, like the political and social variables just discussed, are regionally differentiated. A way of projecting potential conflict would search for places in which the two kinds of factors might overlap. Regions with present or future transboundary externalities (for example, acid rain, pollution of bodies of water) or domains of critical shared resources (for example, international rivers) are examples. These categories correspond roughly with those proposed by Oren Young,[71] but others are possible -- for instance, whether the limiting resources are public, private, or common. The prospect of global climate change introduces additional possibilities, through effects on the global "commons" -- for example, the large-scale shifts in agricultural production or major population dislocation that could be induced by changing sea levels. The relative rank of environmental factors as potential conflict threats are location-specific: for example, transboundary acid rain would rank above sea-level change for an agriculturally dependent, inland downwind nation, but below it for an island state.

To illustrate this approach, we have used the ArcInfo system to convert various environmental databases to map format in order to seek out possible consequences of environmental change. Examples are given in Plates 1 and 2 (see the inside front and back covers). Global warming resulting from the anthropogenic addition of carbon dioxide and other greenhouse gases is expected to increase average annual global temperature by 1-3.5 degrees Celsius in the next century. This will be associated with a rise of several tens of centimeters in static sea level, but the impact of global warming on the intensity of violent storms -- already apparent in some monsoon climates -- will likely exaggerate the impact of that change. Plate 1 is a map, in 10 x 10 km cells, of the human population density in the Ganges-Brahmaputra delta region of Bangladesh. One of the poorest and most crowded areas in the world, the delta has been repeatedly ravaged by typhoons -- some of them with death tolls in the hundreds of thousands. Plate 2 displays topographic data in 1 m elevation intervals.[72] Overlaying the two plates yields the results shown in Table 1. A storm combined with static sea level rise that reached to 2 m elevation could affect between 10 and 15 million people, with displacement or even death as possible consequences.

## Table 1. Ganges-Brahmanputra Delta: Potential Effects of a 5-meter Sea Level Rise or Storm Surge[a]

| Elevation (masl)[b] | Area ($km^2$) | Cumulative Area ($km^2$) | Population | Cumulative Population |
|---|---|---|---|---|
| 0 | 9,183 | 9,183 | 3,387,714 | 3,387,714 |
| 1 | 5,496 | 14,679 | 3,193,517 | 6,581,231 |
| 2 | 15,851 | 30,530 | 9,036,786 | 15,618,017 |
| 3 | 15,483 | 46,013 | 11,730,492 | 27,348,509 |
| 4 | 13,813 | 59,826 | 9,996,673 | 37,345,182 |
| 5 | 11,237 | 71,063 | 10,835,644 | 48,180,826 |

[a]Data obtained by digital superimposition of the maps shown in Plates 1 and 2.
[b]Meters above sea level.

But this case also illustrates the importance of the intersection between environmental and institutional variables. Such storm surges and floods in the past produced large death tolls, but intervention by the Bangladesh government, in the form of coastal engineering and flood shelters, appears to have reduced those risks substantially. State capacity, in other words, is an important modulator of the relationship between environmental change and conflict potential.

This example demonstrates one way of pursuing the analysis. Underlying environmental trends are projected, their regional impacts are mapped, and the results are compared with the geography of various sources of historic or contemporary political, ethnic, or religious tension. If the climate continues to change along its predicted course and the population continues to grow, many more people than are shown in Table 1 will be at risk. In situations of extraordinary vulnerability, it seems wise to ask: Where might refugees go? How are they likely to be received? What preventive steps could be taken to minimize the possibility that one disaster spawns a worse one?

## CLIMATE CHANGE, AGRICULTURE, AND CONFLICT POTENTIAL

Agricultural production is the primary purpose for which "natural" land cover is altered or removed. Much current debate centers on the capacity of food production systems to stay ahead of population growth -- as it has in the past, often counter to prediction. At issue are several key questions: the impact of dietary change due to urbanization and income improvement; whether average yields for important staple crops can match best yields; the capacity of improved agronomy and new technology to intensify production from a fixed or diminishing cropland base; and the sustainability of soil quality and aquifers. Mapping histories (yield, acreage, per capita food supply, food dependence, famine occurrence) may hint at where local or regional problems might arise. Given the world market for staple grains, attention should focus on situations where major shifts in global supply and demand might disadvantage a nation enough to encourage conflict over food resources.[73]

One aspect of regional security is the adequacy of food supplies to feed growing populations. "Food security" is dependent on a broad array of factors, some local and some global. At the local level, these include availability of arable land and of adequate water, population density, and family income. At the global level, world food prices and climate change will be the important determinants.

Where environmental deterioration and overconsumption of water supplies decrease the capacity of local agriculture to meet local needs, people depend more upon food supplied from outside the region. The usefulness of such supplies is limited by the ability of people to pay and, often, by the inability of distribution systems to reach people in need. In extreme cases, local and regional shortages have led to refugee crises or requirements for expensive international military intervention and food aid.

The influence of gradual global climate change[74] on agricultural productivity has become a favorite subject for economic modeling. For example, the work of Nordhaus, employing a Dynamic Integrated Model of Climate and the Economy (dice), has suggested a relatively low cost for a "business as usual" approach to the control of greenhouse gas emissions.[75] His estimates are quite sensitive, however, to assumptions about the damage due to a doubling in the atmospheric $CO_2$ content. It is generally accepted that, in any event, the impacts on agriculture in low-income tropical countries will be more severe than those on the high-productivity agriculture of the higher-latitude oecd nations.

The sensitivity of regional agriculture to gradual global climate change can be inferred from powerful correlations that already exist between large-scale temporal climate modifications and yields. For example, the major agricultural production sectors in Zimbabwe (cereals, pulses, oil crops) experience losses of nearly 10 percent following an El Niño year, corresponding to a 2.6 percent decrease in gdp.[76] These events can be reliably predicted by observations of sea surface temperatures in a region of the southwest Pacific, offering the opportunity to make advance preparations for shortages or even to "hedge" by substituting crops that are relatively unaffected (root crops, tobacco) for those that are severely affected maize).[77]

Recent analyses of the yield variance in the world's major grain crops have produced additional evidence demonstrating the importance of climate. Annual fluctuations are substantial; recent work has shown that the largest variation in cereal grain yields occurs in the developed countries (and in sub-Saharan Africa), and is especially marked for maize. The evidence suggests that as yields press upward in intensive, developed-country agriculture, weather becomes the predominant source of yield variance.[78] El Niño events show a strong influence on U.S. corn yields as well. Precipitation variability (which has increased over the past century) may have a dual impact on regional food security in the developing nations: first by its direct effects on local production, and second through the highly leveraged impact that changing yields in the developed world have on world food prices.

The more important lesson to be drawn from these relationships is that human institutions, like global climate and ecosystems, contain nonlinearities that can amplify modest perturbations into much larger effects. El Niño conditions depend on small anomalies in the temperature profile in the southwest Pacific. These are amplified by larger-scale climate patterns into significantly altered rainfall around the world. That, in turn, may be further amplified, by the nature of national economies and of the global price system, to produce widespread effects on human welfare.

## Box 1. Climate, Food Security, and World Prices: Rice in Indonesia

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An example of the connection between climate, food security, and world prices is found in the influence of El Niño events on rice production and prices. Indonesia, in most recent years, has been a marginal importer or exporter of rice. In El Niño years, however, the relatively drier climate can result in delayed planting of a rice crop and a consequent decrease in the acreage planted for the subsequent crop. Following such episodes in the past, Indonesia has experienced "unexpected" import requirements of up to 3 million tons; following the unusually severe El Niño in 1998, expected imports are upwards of 5 million tons. The world market for rice is so delicately balanced that shifts of that magnitude cause an increase in the world prices of about $159 per ton.[79] The global consequences for many nations are limited, since only about 5 percent of world rice production is traded in international grain markets. Nevertheless, this price instability could have very significant impacts on rice-dependent countries that require substantial imports, and in Indonesia the situation has become so serious that price controls have been imposed to hold domestic prices far below world prices. This creates severe hardships for growers and an incentive for illegal export of commodity-shifting.

Further work on climate change, climate variability, and food production will be important in developing strategies for preventive intervention. The poorest nations of the world are particularly vulnerable to food insecurity: their population profiles are dominated by children, they are especially subject to environmental deterioration, and they often lack the capacity to buffer regional losses in production by purchases in international markets. In Afghanistan, Angola, Ethiopia, Rwanda, Sierra Leone, Somalia, and Haiti, people have suffered from conflicts that have been exacerbated by, and perhaps even partly caused by, food shortages due to environmental factors. When soils deteriorate and deforestation reduces supplies of local wood and water, gatherers must travel farther, and farmers must cultivate more land to produce the same quantity of food. Of course, many different consequences may follow. There may be migration to cities, exacerbating problems that already exist there. Local unrest is another possibility, resulting from conflicts over scarce resources; or diets may become inadequate as a result of falling incomes. Here, as in other situations, state capacity to deal with the consequences of shortage may be the critical element in retaining stability. Mapping rates of change in environmental quality, by examining the percent of land that has already been altered for human purposes but is deteriorating in its capacity to fulfill them, could indicate likely trouble spots.

In at least two ways, agricultural research and agricultural policies vitally affect the stability of developing nations. First, agricultural production increases depend heavily on improving yields on the existing cropland base: between 1960 and 1990, 92 percent of the increase in world cereal grain output came from higher yields, and only 8 percent from additional land. If yield improvement efforts fail, however, there will be pressure to move agriculture "upslope" to less productive soils that require clearing. The result is likely to be accelerating losses in environmental quality. Second, developed-country trade policies often have adverse consequences on the capacity of developing countries to earn agricultural revenue. U.S. sugar quotas, for example, have historically seriously damaged the capacity of Caribbean states to enjoy a natural competitive advantage in a valuable export crop. (These policies, of course, have also had adverse domestic effects that include the disruption of Everglades hydrology and the pollution of Florida Bay, as well as added costs to U.S. consumers.)

Sadly, the international structures responsible for the research that will be needed to support preventive strategies are suffering from donor fatigue. Funding for core support in the CGIAR agricultural research system has decreased alarmingly in real terms over the past several years, though special-project funding has held up better. The United States bears much of the responsibility for this decline, and for the more general reduction in international development aid. The United States now ranks last among OECD countries in developmental assistance allocations as a percent of GNP, and congressional cuts in funds for development and humanitarian assistance are an annual event. Increasing U.S. support for international agricultural research is thus a high-priority form of preventive intervention, and pending U.S. legislative support for such research appears promising.

Nations with high levels of industrial development, or nations that are developing rapidly, often produce adverse transboundary effects on other states. There is the lengthy history of disagreement between Canada and the United States, and between the United States and Mexico, over acid rain.[80] Economic growth in China is being powered largely by supplies of high-sulfur coal, and substantial acid rain problems are projected not only for China but also for the Korean peninsula and Japan.[81] The Japanese are currently supplying some desulfurization technology, but most plants lack scrubbers and the capital cost of installation is very high; furthermore, the Chinese project that in 25 years their electric power sector will still be over 70 percent coal-dependent.[82] In this context, as well as that of limiting the emissions of greenhouse gases, much will depend on whether emissions-trading schemes of the kind envisioned in the aftermath of the Conference of the Parties in Kyoto in December 1997 can be made to work.

In addition to projecting likely regions for regional conflict, attention should be given to particular cases that illustrate how problems might arise in an area where a number of contributing factors converge. An exhaustive survey of such prospective "hot spots" is obviously beyond the scope of this report, but the following examples suggest the kinds of approaches that might be followed.

WATER

Limiting resources may also provide combustible material for local or regional conflict, and among these -- as pointed out earlier -- water is probably the most critical on a global basis. Shared supplies of moving fresh water are particularly likely sources of conflict; in fact, the growing literature of environment/conflict issues probably has more case studies of disputes over water than of any other kind.

Available water in relation to agricultural needs, the geography of control of shared water supplies, and dependence on slowly renewable or nonrenewable aquifers may indicate future difficulty. Recent disputes that could have risen to conflict level include Turkey and Syria over control by the former of the Euphrates and the equally well-studied contests over the Jordan and Palestinian groundwater.[83] Less widely known is the dispute between Mauritania and Senegal over the Senegal River.[84] Other examples include the Ganges and Brahmaputra rivers, involving India, Bangladesh, and Nepal,[85] and the Mekong,[86] involving an array of nations in Southeast Asia.

## Box 2. Cambodia: Transnational Environmental Damage

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The increasingly desperate situation in Cambodia illustrates on way in which transnational environmental contests over resources can lead to political instability and, potentially, to a resumption of internal conflict. Much of the food supply, especially of protein, for the people of Cambodia comes from the fishery of Tonle Sap, one of the world's largest and most productive freshwater lakes. Mountains located northwest of Tonle Sap, near the Thai border, drain into the lake. Their mahogany forests have been heavily expoited by various logging interests that operate primarily from across the border. As a result, hillside erosion has produced heavy siltation of Tonle Sap and placed the fishery in jeopardy. In this case, the environmentally damaging activity is informal, heavily dependent on local arrangement, and virtually immune to traditional interstate negotiation regimes.

In the more familiar instances of struggles over water, two states -- each with claims on the same resource -- engage with one another. Here the incentives and power relations that influence negotiations among "upstream" and "downstream" nations are critical. The former receive most of the water and have control over both its quantity and its quality: they are theoretically free to divert or over-withdraw, or to pollute, or even -- in extreme cases -- to release water and thus create flooding downstream. They are upland states, whereas those located downstream are more often floodplain nations with large, primarily agricultural populations. Compared with the upstream nations, those downstream are more dependent on water from the river and are thus likely to take an aggressive stance in negotiating a share of the resource or seeking agreements about water quality. If they are strong (India with respect to Nepal), they are likely to succeed; if less strong (Mexico with respect to the United States), they may not. If there are strong incentives and a balance of power, conflict may be more likely.

Where upstream nations gain suddenly in population size and water demand, disputes are especially likely to arise. That may be an emerging problem with respect to the Nile. Downstream, Egypt has ambitious irrigation and diversion plans; it can no longer accommodate a growing population in the Nile Valley. Upstream, Ethiopia has emerged from civil crisis with both a rapidly growing population and a healthier rural economy. Its irrigation demands are certain to increase, just as Egypt's are, and Ethiopia is the source of 85 percent of the Nile's water. Enhanced demand is likely to have an impact on the 1959 water-sharing agreement between Egypt and Sudan as well.

In order to identify likely future problem areas, we concentrated on regions of rapid population growth, unreliable or variable precipitation, and identifiable shared sources of water. Southern Africa presents special challenges in this regard. As part of this study, Peter Gleick of the Pacific Institute conducted a field inquiry in international rivers in this area. Contests over water have not been well studied there, yet there are a variety of different patterns of national influence and an array of developing problems.

Southern Africa has an extremely variable climate and hydrologic regime. In the region of the Southern African Development Community, 57 percent of the area receives less than 1200 mm of precipitation per year; more than 20 percent is arid. Precipitation is seasonal, originating mainly from the Indian Ocean in a summer wet season; interannual variation is very high. Dependence on rainfall and river runoff is heavy, and all major rivers are international.

Not surprisingly, water demand is high in the drier urban centers (the Namibian capital of Windhoek, for example) and industrial areas (like the Transvaal of South Africa). These demands have led to proposals that hold heavy promise for generating strong disagreement, if not actual conflict. The South African government has concluded an agreement with Lesotho[87] whereby the latter is building -- entirely with South African funding, at U.S.$2.5 billion for the first phase alone -- a dam and a set of diversion tunnels to transfer water from the Orange River in the Lesotho highlands to the Vaal basin and thereby to the industrial province of Gauteng (the Johannesburg region). Lesotho, one of the world's poorest countries, is entirely surrounded by South Africa; it is the highest point in the southern part of the continent and receives considerable orographic rainfall.

Significant impacts are expected, both on native peoples and on wildlife, but the project will enrich Lesotho. Local opposition to the project is apparently not strong. Water is virtually the country's only marketable good; in this respect Lesotho resembles Laos, which hopes to build a major hydroelectric project for the same reasons. But the Lesotho Highlands diversion (which, according to current plans, will eventually amount to 30 cubic meters/sec) will affect downstream users in central and western South Africa and also in Namibia, and concern over the impact of the project there has been growing.

Namibia is the focus of another controversy, but in quite a different context. The Okavango River, shared by Angola, Namibia and Botswana, is a large river that drains entirely into a large inland delta. Located in Botswana, the Okavango Delta is one of the biologically richest and most renowned ecosystems in the world. The delta is classified as a World Heritage Site; it contains remarkably diverse flora and fauna, and has become a major destination for ecotourism. Thus it is a significant generator of revenue for the Botswanan economy. Earlier plans to divert some of the river's flow to domestic irrigation, urban users, and a large mine were put on hold, partly because of the concerns of the international environmental community.

A series of drought years in Namibia during the early 1990s triggered plans by that country to build a major diversion to serve Windhoek, 250 kilometers away. The proposed level of extraction could have considerable impact on the health of the delta. There is an Okavango River Basin Commission, but no long-term agreement over water allocations or management. Negotiations are under way, but continued drought is likely to reinforce Namibian determination to pursue the development unilaterally. This would violate international principles governing shared watercourses and establish a precedent that could be damaging to the future of other efforts to avoid difficulty in this water-starved region.

OTHER COMMON-POOL RESOURCES

Contests also frequently develop among nations or groups for common-pool resources that lie outside the normal limits of national control (marine fisheries, or the water quality of semi-enclosed seas, for example), and these are other potential sources of regional conflict. One case is the Sea of Japan, which is the site of occasional contests over fishery resources and has also been the receptacle for extensive dumping of nuclear waste from Russia's Pacific nuclear fleet. Proposals for a regional-compact framework may help in resolving both issues.

## 4. Global Challenges

In addition to the regionally differentiated prospects for conflict generation, there are some consequences of population growth and anthropogenic environmental change that could have broadly distributed effects. Global climate change is first among these, but climate change often interacts with other human-induced environmental disruption. Planning for conflict reduction cannot afford to ignore the prospect that such changes may produce unanticipated consequences that raise the risk of intergroup and interstate conflict.

ENVIRONMENTAL CHANGE AND INFECTIOUS DISEASE

Among these consequences is the possibility that climate change, coupled with other forces, will alter the prevalence and seriousness of infectious disease; this will be explored in some detail as an example of the complexity of such challenges. Many infectious diseases have shown strong resurgence in recent years, including tuberculosis, cholera, and malaria; in addition, new viruses (HIV, Ebola, Marburg) have recently appeared for the first time. Major new epidemics, with consequent population displacement, cannot be discounted.[88] The role of climate change, by altering vector distributions, or land use change, by creating ecological harbors for pathogens, can affect the probability of epidemics. So can population growth and added mobility -- first, by pressing humans into environments not previously colonized, where novel pathogens are able to exploit their immunological naiveté; and second, by mixing people over greater distances and at higher frequency. Other environmental changes, in land use and land cover or in regional climate patterns that in turn depend on changes in average global temperature, may create new ecological niches for pathogens and their vectors.[89]

The prospective resurgence of dengue fever in Latin America and elsewhere illustrates the complex character of these relationships. The virus that causes dengue/dengue haemorrhagic fever exists in four serotypes and is transmitted by bites from its mosquito vector, *Aedes aegypti.* This mosquito, once eradicated in a number of countries, has now reappeared in all -- partly because of the abandonment of the use of DDT and partly because of its ability to reproduce in small pools of water that collect in such artifacts of human civilization as discarded tires and tin cans. Its reproduction is limited by temperature; because sustained freezing temperatures kill the larvae and adults, it is marginal in the southern United States. In Mexico, studies on disease prevalence after the reestablishment of *A. aegypti* showed that increased temperature was the most significant risk factor. At higher temperatures, the extrinsic incubation period for the virus goes down, raising the probability of transmission at a given biting frequency. In fact, biting frequently increases at higher temperatures as well, enhancing the risk further. Because dengue had been eliminated over many parts of its range for several decades, its resurgence poses an especially severe threat to populations that now consist entirely of immunologically naive individuals.

The case of malaria transmission and its sensitivity to climate change is in some respects similar. Some of the most interesting consequences relate not to average temperature but to changes in regional weather patterns that are its secondary consequences. We already have some experience with those -- especially the El Niño-Southern Oscillation (ENSO) events, which have far wider consequences than have been generally realized.

Convincing relationships between regional malaria outbreaks and ENSO events have now been established for the Indian subcontinent and for parts of South America. Increases in average global temperature may influence the spread of the disease in several ways. Warming affects the "vectorial capacity" of anopheline mosquitoes -- they may fly faster and longer, encountering more people. It also shortens the incubation period of the sporozoan parasite in the insect vector, so that the percentage of effective mosquito-human encounters rises. It may expand epidemic potential into new areas, by overcoming temperature barriers to the geographical distribution of the vector. That prospect is probably more serious with respect to altitude than with respect to latitude: the altitudinal distribution of mosquitoes characteristically shows sharp temperature limitations. The threat to higher-altitude tropical cities (Nairobi, Mexico City) may be worth special attention in this case, as with dengue. There is a need for research to identify concentrations of people who may be particularly vulnerable to the effect of small changes in average temperature or weather patterns on the biology of pathogens or their vectors.

A good example of the influence of such patterns emerges from studies of malaria incidence in Rwanda. In 1987, an exceptionally warm and wet El Niño year, the increase was greatest (over 500 percent) at altitude; the temperature difference explained most of the variance.[90] Conversely, at low elevations rainfall played the major role. The curve shown in Figure 10 correlates disease incidence with climate, the latter determined by an equation that includes terms for rainfall (lagging by 2-3 months) and temperature (lagging by 1-2 months). This curve gives what the authors describe as the "best fit" to the incidence data, but the incidence peaks nevertheless systematically precede the climate peaks. More general models for the relationship have been developed.[91]

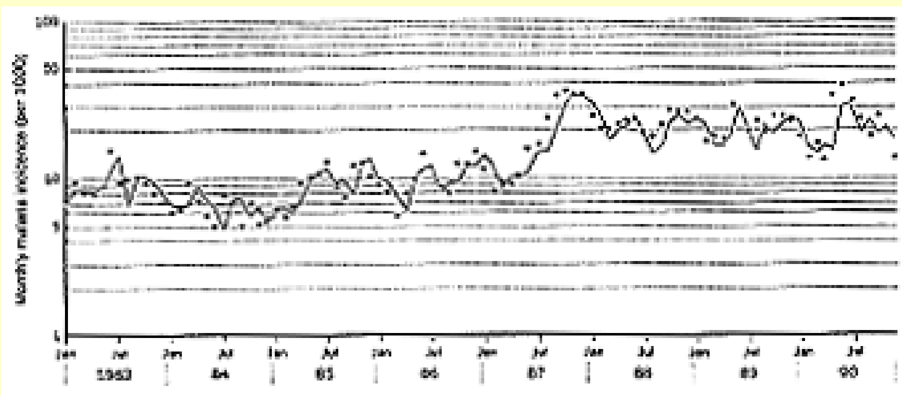

**Figure 10. Monthly incidence of malaria (cases per 1000) in Rwanda (points) potted against a climate variable (solid line) that includes lagged temperature and rainfall data.** Reprinted with permission from Loevinsohn.[90]

The complexity of epidemiological modeling, combined with the uncertainty of interacting climate-change variables, produces a challenging environment for prediction. Among the issues that have to be considered are the ratios between infected, immune, and susceptible persons, and various attributes of the vector: population density; life-cycle and its temperature dependence; and activity level (therefore, biting frequency) and its temperature dependence. The life-cycle of the parasite also appears to be temperature-dependent. Martens[91] has developed integrated assessment models and used them to estimate future climate-change-associated risks from the three most important vector-borne diseases -- malaria, schistosomiasis, and dengue. These estimates yield very large numbers -- an estimated increase in epidemic potential for malaria, for example, of between 10 percent and 30 percent, depending on which climate-change scenario is selected, putting as many as three-quarters of a billion people at risk in the developing world by 2050. Needless to say, such estimates are fraught with uncertainty, but special attention should be given to vulnerable populations in mountainous areas like western China, the East African highlands, and the Andes, where especially altitude-sensitive vectors are found.

It is important to recognize that liability to infectious disease depends heavily on other factors. When people move in significant numbers, as when demobilized armies and refugees migrate in the aftermath of wars, epidemics flourish; thus the influenza outbreak following World War I killed more people than the war. Climate changes may well cause dramatic human dislocation, or bring about ecological adjustments that increase the risk of human infection or indirectly alter human resistance to disease.

A major event in the modern history of infectious disease has been the resurgence of cholera in many places. In 1960, an optimistic epidemiologist wrote: "Further research may show that cryptic or undiagnosed cholera is present in all seasons and years in places like Burma, Nepal, and Thailand; but until this has been demonstrated, Bengal must be regarded as the source of all epidemics. Therefore, should the infection be eliminated from Bengal, it would almost certainly disappear from the world."[92] But epidemics in the 1990s in South America and Africa have killed tens of thousands of people, and the disease is clearly climate-dependent in a number of ways. The case of the South American epidemic is especially instructive. The appearance of the disease in 1991 is attributed to the discharge of ballast in Lima harbor from an Asian vessel. But its nearly simultaneous appearance along the Peruvian coast apparently resulted from warm El Niño surface temperatures like those in the Bay of Bengal.[93] Here as elsewhere, the bacteria are symbiotically associated with green and blue-green algae, where they can remain in uninfective, nonculturable form. When temperature permits an algal bloom, outbreaks are triggered during which infective bacteria may become associated with zooplankton as well.

After the Lima release, cholera soon spread rapidly northward, invading Mexico and becoming established in agricultural villages in Chiapas, where a Stanford group led by Gary Schoolnik has been studying the molecular biology of cholera as well as its relationship to weather and local practices. The picture that is emerging well illustrates the complex interaction between climate change, resulting environmental impacts, human practices, and the behavior of disease organisms. Population growth and poverty in Chiapas, as elsewhere, have tended to push agriculture from relatively fertile lowland sites to more depleted uplands where terracing and fertilization are both required. The terraces create ideal environments in which water can pool. In El Niño years (and the first several years of the 1990s, unprecedently, were El Niño years) southern Mexico is much wetter than usual. These pools were enriched by the addition of nitrates and phosphates from applied fertilizer and developed small-scale algal blooms. It seems highly probable that cholera outbreaks were triggered or at least assisted by these conditions.

The emergence of infectious disease, when coupled with the other factors that encourage it -- population growth and environmental change -- could play a significant role in the development of regional conflict. Epidemics magnify other tragic consequences of population growth and resource depletion, increasing people's vulnerability to inadequate nutrition or other diseases. They also raise the probability of conflict by adding fear of contagion to whatever other ethnic, religious, or historical factors already make different groups hostility-prone.

Future medical refugees, unlike Boccaccio's escapees from the plague in the Florentine Renaissance, will surely not repair to countryside villas and tell one another stories. They are likelier to move *en masse* into neighboring regions or states, there encountering populations whose generalized mistrust and discomfort at being invaded is likely to be amplified by the fear of infection.

Infectious agents now also must be recognized as candidate weapons of terrorism or intragroup hostility. The experiences of the Gulf War and revelations about the extent of biological weapons development in Iraq and in the former Soviet Union remind us that pathogens can be instruments of conflict as well as generators of conflict.[94] The release of sarin in the Tokyo subway system and the discovery of plans by the same sect to attempt a pathogen release remind us that terrorists, too, can avail themselves of such weapons. Thus preventive strategies designed to limit and treat outbreaks of infectious disease carry a "double dividend" in that they may help us cope with deliberate biological warfare as well as deal with epidemics of natural origin.

This raises an important issue with respect to such interventions. In this context, as in others, it is plainly in the national interest of the United States, in concert with other developed nations, to be able to respond effectively to prevent or attenuate local or regional conflicts, most of which will occur in the developing world where population growth, poverty, and environmental change are concentrated. The capacity for effective intervention requires a complex array of elements: military strength adequate to disarm combatants and then keep the peace; food aid if necessary; capacity to remedy environmental damage and protect the public health; and a range of social welfare skills.

Dealing with infectious agents will be an important part of the public health mission, and vaccine technology will be near the forefront of an effective response to such a threat. Yet the necessary technology has been seriously neglected, severely limiting our options for intervention. The result is that pandemic disease, if it involves new or significantly altered agents, is likely to remain out of control, with potentially disruptive effects in any region where it occurs.

The dangerous decline in our capacity to deal with infectious disease has been exposed by the hiv epidemic. The world's vaccine industry is in a state of recession: the few remaining manufacturers are experiencing strong disincentives because of liability problems.[95] Because preventive therapies traditionally have low profit margins, return on research investment is seen as low. For public agencies, at least in the United States, the problem is different. The vaccine development technology that has enjoyed the most historical success entails developing means for growing the virus (sometimes, as in the case of the poliomyelitis virus, this requires difficult cell or organ culture techniques), then working out methods for inactivating or killing the viruses without denaturing surface antigens, and finally developing appropriate formulation and administration schedules. The application of established killed-virus technology, even to a new pathogen, is not basic research but product development. At the National Institutes of Health, which spends $1.5 billion annually on aids research, the small fraction of that budget devoted to vaccine development has gone to "subunit" vaccines, using recombinant dna techniques. No project is now under way, at NIH or anywhere else in the United States, to develop a preventive aids vaccine using the classical killed-virus technology.[96]

Nor is there, despite urgent efforts by knowledgeable scientists, a strategy for mobilizing the kind of multiskilled emergency forces that would be necessary to deal with an incident that simultaneously involved conflict and epidemic. Development of such a capacity would be a "no regrets" strategy, since even if it was not needed for crisis intervention in the developing world, an emergency force would be needed in the event of domestic terrorism using biological warfare. At the moment we are woefully unprepared for either eventuality.

## MEDIATING EVENTS

A number of the examples given in this report suggest the existence of processes that intervene between environmental deterioration and conflict. This is a complex matter, because the potential causal chains are long and often involve interactions among a number of factors.

One feature that appears repeatedly involves the displacement of populations due to environmental degradation and their migration into new areas in which ethnic conflict or struggles over now-inadequate resources follow. A second, suggested in the model developed by Homer-Dixon, relies on decreased economic productivity *in situ,* the consequence of resource depletion. Resulting internal conflicts, born of deprivation, lead to a weakening of the state, a loss of control, and expanding conflict.[97] That a general weakening of state capacity may be related to environmentally induced deprivation is suggested by the powerful correlation between infant mortality and state failure, referred to earlier.

But much more tortuous routes are possible, and need to be considered in any comprehensive treatment of the environment-security linkage. The examples given in Boxes 3 and 4 illustrate that complexity.

It is even possible that some widely distributed effects of global industrial development have had a direct influence on human behavior. Several recent studies have correlated violence or criminal status with body burdens of heavy metals, in particular lead and cadmium. The well-documented effects of lead in retarding intellectual development may result in social circumstances that influence violence-prone behavior, or the effect may be a more direct one. This relationship is obviously highly speculative; we mention it here as a way of alerting ourselves to the improbable -- in our view an essential attitude in any effort to prepare for severe consequences.

## Box 3. Fires, Drought, and Unrest in Indonesia

In the summer and fall of 1997 extremely widespread and intense forest fires developed in Indonesia, especially on Kalimantan and East Sumatra. The resulting particulate hazes, unprecedented in terms of their geographic extent and severity, produced serious health hazards in Malaysian and other East Asian cities, and contributed to a major air disaster. Tension rose between the Indonesian government and those of neighboring states, only partially relieved by an apology form Indonesian President Suharto. The fires resulted from the unfortunate but hardly unique convergence of adverse natural events and inadequate policies. Both smallholders and large landowners use fire as a tool for forest clearing to permit agricultural uses. Exactly how much of the problem is attributable to each is uncertain, but most of the the clearing has been done by corporations preparing oil-palm plantations. Government policies have favored the granting of land concessions for these purpose, especially to politically well-connected enterprises, and the regulation of clearing practices is centralized in distant Javanese ministries with little capacity to control matters on the ground. This gridwork of dysfunctional incentives encountered an unusually dry El Niño season, with the result that burning got out of control and spread widely -- even settling into peat bogs, where the fires became chronic.

The drought also produced drastic reductions in rice production, presenting government planners with a dilemma. As described in Box 1, the export/import status of Indonesian rice is highly nonlinear. The government needs to make rice available to its citizens, but Indonesia's import needs drive world prices up. If the government controls domestic prices below world prices for the benefit of consumers, it runs the risk of wholesale illegal exports (not difficult in a nation consisting of 13,000 islands) and supplies farmers with incentives to shift away from controlled, staple crops to others for which they can get world prices. The food problem is exacerbated by a leadership crisis, involving both a currency collapse and a change of government. A careful and moderately optimistic case study of Indonesia done under the auspices of the Toronto/AAAS program in 1997[98] would now seem outdated: the prospect of acute civic disorder is high unless inflation and exchange rates can be brought under control.

In the relationship between environmental quality and regional conflict, there is also powerful positive feedback. If we are right, environmental degradation may lead to conflict; and surely wars degrade the environment. Indeed, sometimes environmental destruction has been part of conflict strategy, as in the widespread application of defoliants by the United States during the Vietnam conflict -- although international law now bans such use. In the intranational wars fought in Rwanda and Liberia, it is difficult not to conclude that environmental destruction was both cause and effect. The withholding of resources, or the threat of it, is used -- perhaps less often than one might expect in the case of water (note the reluctance of Turkey, even at a time of great hostility, to interrupt the flow of the Euphrates to Syria), and more frequently in the case of food. According to one assessment, food deprivation was used as a weapon in hostilities involving 29 nations during 1993.[99]

## Box 4. Japanese Tires and Texas Mosquitoes

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In 1985, a shipment of tires from Japan destined for recycling in U.S. plants arrived by sea in the port of Houston. After they were loaded at the Japanese dock, some of the tires had filled with pools of water, as tires will; and some mosquitoes had laid eggs in them, as mosquitoes will. The species -- the Asian Tiger Mosquito, *Aedes albopictus* -- thus became an alien invader that has spread from the point of introduction to occupy much of the Gulf Coast. It is described as a promiscuous biter and could be an effective vector of the virus responsible for dengue fever, as is its close relative, *Aedes aegypti*. The difference is that the exotic species can enter diapause in the winter and thus colonize cold climates; *A. albopictus* is already a nuisance pest for mosquito control officers in New Jersey and Illinois. This complex chain of causality involving Japanese tire manufacturers and U.S. recycling is a classic case of economic globalization and its impact on the redistribution of organisms around the world -- an accelerating trend that affects environmental quality and, as here, human health.

Special attention may also need to be given to the fate of "contained" countries, in particular the world's island nations, where resource scarcity has worked desperate hardship on growing populations. Haiti may be the Easter Island of contemporary times: it is 98 percent deforested and has lost much of the fertility of its soils. In a somewhat analogous predicament centuries ago, the Easter Islanders had no place to go, and perished. The Haitians are moving to the United States. Special attention should also be paid to "overlap" regions -- places where critically limiting resources may force mass movements of people into areas where they come into contact with traditionally hostile groups.

### 5. Preventive Investment: A Summary of Opportunity

One theme of the Carnegie Commission is the identification of areas in which it may be possible to practice "preventive defense" or "preventive investment." In this final section, we return to some of the major vectors of environmental change and their potential links to conflict, and explore what kinds of new knowledge might help us intervene constructively.

In many regions of the world, as our analysis suggests, historical tensions based on political, ethnic, or cultural differences or on the instability of governing institutions are added to stresses produced by environmental deterioration and an imbalance between resources and human needs. An appropriate preventive strategy might involve identifying this second set of factors and placing responsibility for analysis and amelioration in the hands of technical experts. That would reduce the likelihood of conflict by creating an arena for resolution that is neither political nor confrontational; and if the analysis is successful, it could provide the basis for negotiated solutions that avoid historical sources of tension.

Preventive strategies need to consider several sources of difficulty. First, ecological and geographical features that are important determinants of environmental status almost never correspond to the boundaries of nation-states. Thus, even on a regional scale, resolutions cannot be worked out through the traditional modes to which state actors are accustomed. Although solutions cannot be mandated or implemented in national terms, international cooperation can be important in directing participants toward political solutions.

Second, major developments in technologies that affect the environment are increasing in frequency and in influence -- and they often trigger higher-order effects that may be important in the design of conflict prevention strategies. The Law of Unintended Consequences, in other words, has to be part of prediction. For example: in the second (post-Green Revolution) generation of agricultural technology, increasing emphasis will be placed on yield-increasing and labor-sparing systems. In rice, direct-seeded varieties are replacing hand-transplanted and hand-weeded varieties. Not only will this shift increase herbicide use, with possible effects on human and ecosystem health, it will also accelerate the movement of people from farm to city, and thus produce a whole suite of other changes: in energy requirements, in population growth rate, and so on.

Third, the focus of concern has clearly shifted from interstate to civil conflict, and from the "Great Power" nations of the industrial world to the poorest of the developing countries. We have already mentioned the relative lack of coping capacity in such states, and the need for new kinds of regional or international institutions to deal both with crises having high conflict potential (large-scale migrations and infectious disease epidemics, for example). It will be cheaper to forestall civil disorder with timely technological assistance or dispute resolution mechanisms than to disarm the combatants once the confrontation has begun.

Can we identify areas in which there are special prevention opportunities related to environment/population/resources? Two of the examples discussed above provide inviting models. The first involves the status of water (specifically, rivers) as an international common-property resource. In Southern Africa, where water availability is especially critical, there are a number of internationally shared rivers about which there is no firm allocation agreement. The Okavango River, discussed above, is one such case. Despite the existence of a multibasin authority (OKACOM) involving Angola, Namibia, and Botswana, there is no long-term agreement. Namibia's proposed diversion plan is plainly in violation of the principles developed by the International Law Commission and has not been considered by OKACOM. The situation will become even more urgent if further drought persuades Namibia to proceed with the withdrawal without an agreement. Other Southern Africa rivers and regions (the Zambezi, the Lesotho Highlands Project) present many of the same difficulties.

In such cases an international prevention strategy might focus on assisting with the development of a multinational basin authority and the design of allocation and withdrawal rules. The problem here is institutional rather than technical: there is no structure for agreement, but there does appear to be adequate water to meet all present national needs. A secondary kind of intervention would involve assistance in the development of technologies for increasing the efficiency of water utilization and in the development of crop varieties with increased resistance to stress. It is not difficult to predict where problems of this kind are likely to develop, and the cost of preventive intervention should be low.

Among the most severe environmental threats in the developing world is the expansion of agriculture onto marginal lands, when yields on existing cropland fall behind the growth of local populations. The consequences are manifold, and all bad. The movement is often "upslope," into natural areas better suited to other land cover; the result is deforestation, which reduces fuelwood resources and may eliminate important ecosystem services that support (for example) water quality. As populations have to farm more land and travel farther for essential resources, the value of children as household assets increases, and that may drive further population growth.[100]

Thus there is much at stake in ensuring that local and regional food yields keep pace with population: it keeps people fed and confines agriculture so as to prevent further environmental deterioration. Areas of special vulnerability are not difficult to pinpoint. The rice and wheat cropping systems of the Indo-Ganges, in the Punjab region of India, support one of the largest and most densely concentrated human population in the world. There are serious questions about the sustainability of present practices, and the area is vulnerable to serious food shortages, with consequent migration and potential conflict.

Yet the technology base for yield improvement, here and elsewhere, is very thinly supported. The Consultative Group on International Agricultural Research, through its sixteen world centers, sponsors much of the relevant research. It is funded by an array of foundation and government donor organizations, but by any standard the two centers that deal with staple cereal grains -- CIMMYT in Mexico for wheat and maize, and IRRI in the Philippines for rice -- have very modest support for research programs that have primary responsibility for improving the yield of what most people in the world eat. As a preventive investment opportunity for conflict reduction, it is highly leveraged. Investment in agricultural enhancement and in rural development are likely to be helpful. There is increasing evidence that improvements in welfare in the rural sector precede general economic improvement in most developing societies.

We believe that special notice should be given to those "domains of unpredictability" in which there is reason to expect highly nonlinear responses to change and for which data are in short supply. The impact of climate change is an especially vivid example. We have no idea whether, or how, the unprecedented warm and stable climate in which we have lived for ten thousand years will end. Perhaps the predicted "slow ramp" of global warming will continue; or perhaps climate history will repeat itself, giving us a sudden plunge out of our present warm interglacial.

Even under the assumption of gradual warming there are uncertainties. How much will agriculture and other economic sectors be affected? The answer depends not only on the slope of the warming ramp but on assumptions about the extent of damage and about human "adaptability." What are the likely secondary climate effects -- changes in the intensity or frequency of violent storms, or in the occurrence of larger-scale events like El Niño? And what about the next layer of consequences: the spread of infectious disease, or the enforced movement of human populations?

These uncertainties argue strongly for more research, not only on earth systems and the mechanisms of climate change but on land-use changes, ecosystem services, and the demand of human populations for resources. It is not difficult to speculate, as we have here, about environmental quality and its relationship to regional security; and certainly some places and circumstances cry out for special attention. But to know the future well enough to discern developing problems in time to practice preventive intervention will require more knowledge than we have now -- much more.

The threat of future conflict is firmly located in the developing world -- where crowded peoples in poor nations are at risk from the pace of environmental change, the rapid growth in their own populations, the growing threat of infectious disease, and an array of ethnic and tribal hostilities. For the United States and the other rich nations, this calls for a research investment quite different from the ones we are now accustomed to making. We will need to give much more attention to the questions of resource availability, environmental deterioration, and development.

Finally, any analysis of environment and conflict that selects a sufficiently distant horizon needs to confront the "unthinkable" scenarios -- if only as a stimulus to motivate the development of preventive strategies. It is surely possible that at some point, one or several "developing" states might, through their own growth activities, present an environmental threat perceived as so serious that "developed" states, having pursued other avenues of resolution in vain, decide to intervene militarily to prevent the developing nations from polluting or cutting their forests or exploiting some common-pool resource. The prospect of a new "ecological colonialism," enforced by military technology, is even grimmer than a somewhat likelier alternative: that developing states, having failed to address by other means what seem to them desperately inequitable resource deficits, attack one another, or even some of the richer nations, in a series of local or regional conflicts that flare up rapidly and defeat efforts of the world community to manage them. The most powerful nations of the world would then confront a chronic kind of moral agony that would be difficult to endure. That prospect alone should be enough incentive for a substantial investment in preventive research.

**Notes and References**

1. But see Ehrlich, P. R. 1989. "The Global Commons and National Security." In Berger, A., Schneider, S., and Duplessy, J. C. (eds.), *Climate and Geo-Sciences: A Challenge for Science and Society*. Dordrecht: Kluwer, 553-562.

2. Levy, M. A. 1995. "Is the Environment a National Security Issue?" *International Security* 20: 35-62. An exchange of views between Levy and Homer-Dixon on these issues is to be found in *International Security* 20: 189-198.

3. For an objective summary of this case, see Gleditsch, N. P. 1997. "Environmental Conflict and the Democratic Peace." In Gleditsch, N. P. (ed), *Conflict and the Environment.* Dordrecht: Kluwer. A new effort to introduce quantitative comparative assessments of the relationships among environmental stress, population density, and conflict has been undertaken by the International Peace Research Institute in Oslo. This ambitious project found significant correlations of domestic armed conflict with deforestation, land degradation and water availability, alone and in combination with high population density. Economic and political factors, however, were more important predictors. See: Hauge, T., and Ellingsen, T. 1998. "Beyond Environmental Scarcity: Causal Pathways to Conflict." *Journal of Peace Research* 35: 299-317.

4. Homer-Dixon, T. F. 1991. "On the Threshold: Environmental Changes as Causes of Acute Conflict." *International Security* 16: 76-116.

5. Homer-Dixon, T. F. 1994. "Environmental Scarcities and Violent Conflict." *International Security* 19: 15-40.

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8. Deudney, D. 1990. "The Case Against Linking Environmental Degradation and National Security." *Millennium: Journal of International Studies* 19: 461-476.

9. Homer-Dixon, T. F. 1994. "Environmental Scarcities and Violent Conflict" (note 5 above), p. 6.

10. See Sivard, R. L. 1992. *World Military and Social Expenditures 1989.* Washington: World Priorities. For more recent years, see *Stockholm International Peace Research Institute Yearbooks.* London: Oxford University Press.

11. See, for example, Carnegie Commission on Preventing Deadly Conflict. 1997. *Preventing Deadly Conflict*, Executive Summary of the Final Report, pp. 3-4. Washington, DC: Carnegie Commission on Preventing Deadly Conflict.

12. Dasgupta, P. 1996. "Ecological Economics in Poor Countries: The Current State and a Programme for Improvement." sarec *Seminar on Research Cooperation towards 2015.* Stockholm.

13. Suhrke, A. 1994. "Environmental Degradation and Population Flows." *Journal of International Affairs* 47: 473-496.

14. For a thoughtful review of these and related arrangements, see Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action.* Cambridge: Cambridge University Press.

15. Goldstone, J. 1996. In "Advancing the Environmental Security Debate." *Environmental Change and Security Project Report 2*. Washington, D.C.: Woodrow Wilson International Center for Scholars, pp. 66-71.

16. This approach has produced a rich yield of literature. The Environmental Change and Security Project at the Woodrow Wilson International Center for Scholars has produced several reports and useful summaries of activities under way elsewhere. The Swiss Peace Foundation has sponsored the Environment and Conflicts Project, an international program that has produced a series of working papers. The Project on Environment, Population and Security at the University of Toronto, cosponsored by the American Academy of Arts and Sciences (AAAS), is directed by Thomas Homer-Dixon and has produced studies on regional problems in, among other regions, Rwanda, Chiapas (Mexico), and Gaza, as well as on more general relationships between environment and security. The AAAS/Toronto group also sponsors the Project on Environmental Scarcities, State Capacity and Civil Violence; codirected by Homer-Dixon and Jeffrey Boutwell, it has examined problems in Indonesia and China. A significant project is under way at the International Peace Research Institute in Oslo. The U.S. Department of Energy is initiating a program, and its national laboratories -- especially Lawrence Livermore National Laboratory -- are major participants. Lawrence Livermore sponsored, with Stanford and several other universities, a conference on the subject in Monterey, California, in December, 1996. See Gilmartin, T. J., Allenby, B. R., and Lehmann, R. F. 1996. *Environmental Threats and National Security: An International Challenge to Science and Technology*. Livermore, CA.: Lawrence Livermore National Laboratory.

17. For a review and analysis of this very old proposition, see Ember, C., Ember, A. and Russett, B. 1992. "Peace Between Participatory Polities: A Cross-Cultural Test of the 'Democracies Rarely Fight Each Other' Hypothesis." *World Politics* 44: 573-599.

18. Gleditsch, N. P. 1998. "Armed Conflict and the Environment: A Critique of the Literature." *Journal of Peace Research* 35: 381-400.

19. Homer-Dixon, T. F. 1995. "The Ingenuity Gap: Can Poor Countries Adapt to Resource Scarcity?" *Population and Development Review* 21: 587-612.

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23. For an evaluation of methods and a review of the estimation problems, see Downton, M. W. 1995. "Measuring Tropical Deforestation: Development of the Methods." *Environmental Conservation* 22: 229-240.

24. The impact of deforestation on the occurrence of armed conflict is significant, though only for smaller conflicts. Hauge, W., and Ellingsen, T. 1998 "Beyond Environmental Scarcity: Causal Pathways to Conflict" (note 3 above).

25. For a comprehensive summary, see Daily, G. (ed.) 1997. *Nature's Services: Societal Dependence on Natural Ecosystems.* Washington: Island Press.

26. Intergovernmental Panel on Climate Change. 1996. *Climate Change 1995: The Science of Climate Change.* New York: Cambridge University Press. See also Morgan, G., and Keith, D. W. 1995. "Subjective Judgments by Climate Experts." *Environmental Science and Technology* 29: 468-476.

27. But see Intergovernmental Panel on Climate Change, op. cit.

28. For example, Nordhaus, W. D. 1994. *Managing the Global Commons: The Economics of Climate Change.* Cambridge: mit Press.

29. Keeling, C. D., *et al.* 1996. "Increased Activity of Northern Vegetation Inferred from Atmospheric $CO_2$ Measurements." *Nature* 382: 146-149.

30. climap Project Members. 1981. *Geol. Soc. Am. Map Chart Ser.* 36.

31. The especially valuable Greenland ice cores result from two drilling projects, one European (grip), the other American (gisp). For a comparison between the two cores and cores taken from North Atlantic sediments, see McManus *et al.* 1994. "High-Resolution Climate Records from the North Atlantic during the Last Interglacial." *Nature* 371: 326-329.

32. These abrupt state changes, called Dansgaard-Oeschger (d-o) events after the paleoclimatologists who described them, entail large as well as rapid temperature shifts. The Greenland record shows that for the past 115,000 years, ending with the last major cold burst (the Younger Dryas, which began 11,000 years before present [ybp] and lasted about 1500 years), there were frequent shifts between very cold states and warmer ones that approached but did not reach the temperatures characteristic of the Earth's present climate.

33. The primary report on the grip core is found in Dansgaard, W., *et al.* 1993. "Evidence for General Instability of Past Climate from a 250 kyr Ice-Core Record." *Nature* 364: 218-220. The gisp core is described in Taylor, K. C., *et al.* 1993. "The 'Flickering Switch' of Late Pleistocene Climate Change." *Nature* 361: 432-436, and Meese *et al.* 1994. "The Accumulation Record from the gisp2 Core as an Indicator of Climate Change Throughout the Holocene." *Science* 266: 1680-1682. Figure 2 is adapted from *Climate Change 1995* (note 26 above).

34. Wood remains in New Zealand glacial moraines that are far below the present glaciers have been

dated to 11,000 ybp, consistent with the Younger Dryas glaciation recognized in European and Greenland records. Recent analysis of sediment cores in the Santa Barbara Channel reveals pulses of biological activity that correspond to periods in which oxygen-rich surface waters were cold enough, and therefore dense enough, to sink and provide for the activity of living organisms. These presumed "cold periods" match up almost perfectly with the dates of d-o cold events.

35. Benson, L., *et al.* 1997. "Nearly Synchronous Climate Change in the Northern Hemisphere During the Last Glacial Termination." *Nature* 388: 263-265.

36. For an account of the relationship between ocean circulation and climate change, see Broeker, W. S. 1998. "Thermohaline Circulation, the Achilles Heel of Our Climate System: Will Man-made $CO_2$ Upset the Balance?" *Science* 278: 1582-1588.

37. Oppenheimer, M. 1998. "Global Warming and the Stability of the West Antarctic Ice Sheet." *Nature* 393: 325-332.

38. Scherer, R. P., *et al.* 1998. "Pleistocene Collapse of the West Antarctic Ice Sheet." *Science* 281: 82-85.

39. The active programs support two telescopes (Spacewatch, under construction in New Mexico, and the Near Earth Asteroid Tracking program -- neat -- in Hawaii) and the Defense Department's Project Clementine, whose mission includes intercepting asteroids with small, high-speed probes.

40. In less-developed societies, biomass burning (fuelwood and dung) is important, but this noncommercial use probably accounts for no more than 10 percent of the world total.

41. The first limb of the inverted U essentially disappears if all energy (including biomass) is included; that is because even the very dirty early stages of commercial energy development fail to cause an increase in energy intensity because they replace (through electrification, etc.) highly inefficient household use of wood or charcoal. These issues are reviewed in Goldemberg, J. 1996. *Energy, Environment and Development*, pp. 77-79. London: Earthscan.

42. Grossman, G. M., and Krueger, A. B. 1992. "Environmental Impacts of a North American Free Trade Agreement." In Garber, P., *et al.* (eds.), *The U.S.-Mexico Free Trade Agreement.* Cambridge: mit Press.

43. Keeling, C., *et al.* 1995. "Interannual Extremes in the Rate of Rise of Atmospheric Carbon Dioxide Since 1980." *Nature* 375: 666-670.

44. See, for example, Pimentel, D., *et al.* 1994. "Environmental and Economic Costs of Soil Erosion and Conservation Benefits." *Science* 267: 1117-1122; and Brown, L. 1994. *The State of the World 1994.* New York: W. W. Norton.

45. The conclusions of Pimentel *et al.* were strongly challenged by Crosson, P. 1994. "Soil Erosion Estimates and Costs." *Science* 269: 461-463.

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47. Likens, G. E., Driscoll, C. T., and Buso, D. C. 1996. "Long-Term Effects of Acid Rain: Response and Recovery of a Forest Ecosystem." *Science* 272: 244-246.

48. Smil, V. 1994. "How Many People Can the Earth Feed?" *Population and Development Review* 20: 255-292.

49. For a discussion of these prospective limitations, see Ehrlich, P. R., Ehrlich, A. H., and Daily, G. C. 1994. "Food Security, Population, and Environment." *Population and Development Review* 19: 1-32.

50. It is not made clear how the loss of biodiversity -- that is, extinction -- can be reversed with rational agronomic practices.

51. Waggoner, P. E. 1996. "How Much Land Can Ten Billion People Spare for Nature?" *Daedalus* 125: 73-93.

52. For a treatment of this issue and one proposed solution, see Barton, J., *et al.* 1997. "A Model Protocol To Assess the Risks of Agricultural Introductions." *Nature/Biotechnology* 15: 845-848.

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54. Postel, S. L., Daily, G. C., and Ehrlich, P. R. 1996. "Human Appropriation of Renewable Fresh Water." *Science* 271: 785-788.

55. Rosegrant, M. W. 1997. *Water Resources in the Twenty-first Century: Challenges and Implications for Action.* International Food Policy Research Institute: Food, Agriculture, and the Environment Discussion Paper #20.

56. For an account of such arrangements see Ostrom, E. 1992. *Crafting Institutions for Self- Governing Irrigation Systems.* San Francisco: Institute for Contemporary Studies Press.

57. The problem is not always overappropriation. Sometimes actions (or inaction) by an upstream nation of the opposite kind can produce downstream flooding, as has happened in Bangladesh as a result of policies pursued in India and China.

58. See, for example, Bailey, J. L. 1996. "Hot Fish and (Bargaining) Chips." *Journal of Peace Research*

33: 257.

59. An excellent account of the problems in this area can be found in Peterson, M. J. "International Fisheries Management." In Haas, P. M., Keohane, R. O., and Levy, M. A. 1993. *Institutions for the Earth: Sources of Effective International Environmental Protection.* Cambridge: mit Press.

60. Of course, environment-security interactions occur on a two-way street. Our focus is on how environmental degradation can lead to conflict -- but conflict also amplifies losses of environmental quality. This reciprocal interaction is most obvious in open warfare, but there are subtler effects as well. Environmental damage can result from military preparations; conflict also generates uncertainties about property rights, which in turn interferes with the functioning of markets and adds to the difficulty of internalizing environmental costs.

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63. May, M. 1996. "Rivalries Between Nuclear Power Projectors: Why the Lines Will Be Drawn Again." Center for International Security and Arms Control, Stanford University.

64. Lonergan, S. 1997. "Global Environmental Change and Human Security." *Change* 5: 1-6.

65. In addition to the Stanford members of the Carnegie task force, the group included Peter Gleick, Pacific Institute; Jack Goldstone, University of California at Davis; Alex George, Stanford; Ronnie Lipschutz, University of California, Santa Cruz; and P. J. Simmons, Carnegie Endowment for International Peace.

66. In fact, one study of the historical relationship between demographic pressure and conflict shows that population growth, though not population density, significantly increases the probability of militarized conflict. See Tir, J., and Diehl, P. F. 1998. "Demographic Pressure and Interstate Conflict: Linking Population Growth and Density to Militarized Disputes and Wars, 1930-89." *Journal of Peace Research* 35: 319-339. This finding may underscore the possibility that it is the shape of the demographic profile and not the number of people that disposes to conflict.

67. Cairncross, F. 1994. "Environmental Pragmatism." *Foreign Policy* 95: 35-52.

68. Smil, V. 1992. "Environmental Change as a Source of Conflict and Economic Loss in China." Occasional Paper, Peace and Conflict Studies Program, University of Toronto.

69. On the general problem of "environmental refugees," see Myers, N., and Kont, J. 1995. *Environmental Exodus: An Emergent Crisis in the Global Arena*. Washington, D.C.: Climate Institute.

70. Homer-Dixon, T. F., *et al.* "Environmental Change and Violent Conflict" (note 53 above). See also Hassan, S. 1992. "Environmental Sources of Conflict in the South Asian Subcontinent." *Disarmament* 15: 79-95.

71. Young, O. 1994. *International Governance: Protecting the Environment in a Stateless Society*. Ithaca: Cornell University Press.

72. The elevation dataset is from USGS gtopo30 Digital Elevation Model, in which each 1 km square is represented by a single average value. The dataset is produced through conversion of the National Imagery and Mapping Agency's Digital Terrain Elevation Data, which is packaged in "tiles" 120 km square. The sharp edges of the green and yellow areas at the center of the map are artifacts of this conversion. The yellow area also indicates elevations 1 m higher than they actually are, and therefore the figure for the number of people affected at 2 m above sea level in Table 1 (p. 40) is an underestimate.

73. On the other hand, deprivation may encourage a nation to engage constructively with nations it has traditionally mistrusted.

74. This term is employed to designate the scientific consensus (see Intergovernmental Panel on Climate Change (note 26 above) that average global temperature will rise steadily, reaching 1.5-3 degrees Celsius warmer than the present temperature late in the next century. Other, more dynamic climate futures are possible, perhaps even likely.

75. Nordhaus, W. 1994. *Managing the Global Commons* (note 28 above).

76. Heal, G. and Y. Lin. 1998. "El Niño and Agriculture in Zimbabwe." Unpublished manuscript.

77. During the summer of 1997, forecasts by the Southern African Development Community and by the UN Food and Agriculture Organization, combined with active agricultural extension work in Zimbabwe, appears to have resulted in significant behavioral change at the farm level; the same is reported for Brazil, another nation in which El Niño has significant yield effects (Lovejoy, T., personal communication, Smithsonian Institution, November 1997).

78. Naylor, R., Falcon, W. P., and Zavaleta, E. 1997. "Variability and Growth in Grain Yields, 1950-94: Does the Record Point to Greater Instability?" *Population and Development Review* 23: 41-58.

79. For an account of this price situation, see Timmer, P. 1986. *Getting Prices Right: The Scope and Limits of Agricultural Price Policy*. Ithaca: Cornell University Press.

80. See, for example, Wirth, J. D. 1996. "The Trail Smelter Dispute: Canadians and Americans Confront Transboundary Pollution, 1927-41." *Environmental History* 1: 34-51.

81. For a comprehensive survey of this important problem, see Downing, R. J., Ramankutty, R., and Shah, J. J. 1997. *Rains-Asia: An Assessment Model for Acid Deposition in Asia*. (Washington: World Bank).

82. This figure was supplied by Chinese government officials at a U.S./Japan/China Conference on Sustainable Energy Development cosponsored by Stanford, the New Energy and Industrial Technology Development Organization (NEDO), and Tschinghua University in Beijing, July 1996. An interesting private comment regarding the Japanese support of scrubber technology was made by one of the Japanese representatives. Although he stressed his nation's interest in limiting the possibility of west-to-east sulfur transport, he pointed out the Japanese concern for keeping China out of the market for Middle East oil in the western Pacific.

83. For a recent summary see Lowi, M. R. 1996. "Political and Institutional Responses to Transboundary Water Disputes in the Middle East." In *Environmental Change and Security Project Report*, pp. 5-8. Washington, DC: Woodrow Wilson Center.

84. Homer-Dixon, T. F. 1994. "Environmental Scarcity and Intergroup Conflict." In *World Security: Challenges for a New Century*, pp. 290-313. New York: St. Martin's Press.

85. Crow, B. 1995. *Sharing the Ganges.* New Delhi: Sage Publications.

86. See the case study in Stoett, P. J. 1995. *Atoms, Whales and Rivers: Global Environmental Security and International Organization.* New York: Nova Science Publishers.

87. South African pressure on the Lesotho government has recently increased, and the future of this project is uncertain.

88. See, for example, Garrett, L. 1994. *The Coming Plague: Newly Emerging Diseases in a World Out of Balance*. New York: Farrar, Straus & Giroux; Lederberg, J. ed. 1992. *Emerging Infections.* (Washington: National Academy Press); Pirages, D. 1996. "Microsecurity: Disease Organisms and Human Well-Being." In *Environmental Change and Security Project*, Issue 2: 9-14. Washington: Woodrow Wilson Center.

89. Martin, P. H., and Lefebvre, M. G. 1995. "Malaria and Climate: Sensitivity of Malaria Potential Transmission to Climate." *Ambio* 24: 200-207.

90. Loevinsohn, M. E. 1994. "Climatic Warming and Increased Malaria Incidence in Rwanda." *Lancet* 343: 714-718.

91. See, for example, the approach in Martens, W. J. M. 1997. *Health Impacts of Climate Change and Ozone Depletion: An Eco-Epidemiological Modelling Approach.* Ph.D. Thesis, Maastricht University.

92. Cockburn, T. A., and Cassanos, J. G. 1960. "Epidemiology of Endemic Cholera." *Public Health Reports* 75: 791.

93. Colwell, R. R. 1991. "Global Climate and Infectious Disease: The Cholera Paradigm." *Science* 274: 2025-2031.

94. Daily, G. C., and Ehrlich, P. R. 1996. "Impacts of Development and Global Change on the Epidemiological Environment." *Environment and Development Economics* 1: 311-346.

95. For an account of the liability problems involved in international vaccine administrations, see Wilson, J. P. 1995. *International Lawyer* 30: 783.

96. When asked why not, NIH officials respond that their mission does not include product development. The Department of Defense, which has an important mission in protecting U.S. military personnel in overseas locations where HIV infection rates are high and where different viral strains may be endemic, had a killed-virus HIV vaccine project with an Austrian firm, but that has been suspended.

97. Homer-Dixon, T. F. "Environmental Scarcities and Violent Conflict" (note 5 above).

98. Barber, C. V. 1997. *The Case Study of Indonesia.* Project on Environmental Scarcities, State Capacity and Civil Violence. Boston: American Academy of Arts and Sciences, Committee on International Security Studies.

99. Messer, E. 1993. "Food Wars: Hunger as a Weapon of War in 1993." In Uvin, P. *The Hunger Report 1993,* World Hunger Program, Brown University.

100. Dasgupta, P. 1995. "Population, Poverty, and the Local Environment." *Scientific American*, 272: 40-45.

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