

Global climate change and health: an old story writ large

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Introduction

The long-term good health of populations depends on the continued stability and functioning of the biosphere's ecological and physical systems, often referred to as life-support systems. We ignore this long-established historical truth at our peril: yet it is all too easy to overlook this dependency, particularly at a time when the human species is becoming increasingly urbanized and distanced from these natural systems. The world's climate system is an integral part of this complex of life-supporting processes, one of many large natural systems that are now coming under pressure from the increasing weight of human numbers and economic activities.

By inadvertently increasing the concentration of energy-trapping gases in the lower atmosphere, human actions have begun to amplify Earth's natural greenhouse effect. The primary challenge facing the world community is to achieve sufficient reduction in greenhouse gas emissions so as to avoid dangerous interference in the climate system. National governments, via the UN Framework Convention on Climate Change (UNFCCC), are committed in principle to seeking this outcome. In practice, it is proving difficult to find a politically acceptable course of action—often because of apprehensions about possible short-term economic consequences.

This volume seeks to describe the context and process of global climate change, its actual or likely impacts on health, and how human societies should respond, via both adaptation strategies to lessen impacts and collective action to reduce greenhouse gas emissions. As shown later, much of the resultant risk to human populations and the ecosystems upon which they depend comes from the projected extremely rapid rate of change in climatic conditions. Indeed, the prospect of such change has stimulated a great deal of new scientific research over the past decade, much of which is elucidating the complex ecological disturbances that can impact on human well-being and health—as in the following example.

The US Global Change Research Program (Alaska Regional Assessment Group) recently documented how the various effects of climate change on aquatic ecosystems can interact and ripple through trophic levels in unpredictable ways. For example, warming in the Arctic region has reduced the amount of sea ice, impairing survival rates for walrus and seal pups that spend part of their life cycle on the ice. With fewer seal pups, sea otters have become the alternative food source for whales. Sea otters feed on sea urchins, and with fewer sea otters sea

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urchin populations are expanding and consuming more of the kelp that provides breeding grounds for fish. Fewer fish exacerbate the declines in walrus and seal populations. Overall, there is less food available for the Yupik Eskimos of the Arctic who rely on all of these species.

Global climate change is thus a significant addition to the spectrum of environmental health hazards faced by humankind. The global scale makes for unfamiliarity—although most of its health impacts comprise increases (or decreases) in familiar effects of climatic variation on human biology and health. Traditional environmental health concerns long have been focused on toxicological or microbiological risks to health from local environmental exposures. However, in the early years of the twenty-first century, as the burgeoning human impact on the environment continues to alter the planet's geological, biological and ecological systems, a range of larger-scale environmental hazards to human health has emerged. In addition to global climate change, these include: the health risks posed by stratospheric ozone depletion; loss of biodiversity; stresses on terrestrial and ocean food-producing systems; changes in hydrological systems and the supplies of freshwater; and the global dissemination of persistent organic pollutants.

Climate change and stratospheric ozone depletion are the best known of these various global environmental changes. Human societies, however, have had long experience of the vicissitudes of climate: climatic cycles have left great imprints and scars on the history of humankind. Civilisations such as those of ancient Egypt, Mesopotamia, the Mayans, the Vikings in Greenland and European populations during the four centuries of Little Ice Age, all have both benefited and suffered from nature's great climatic cycles. Historical analyses also reveal widespread disasters, social disruption and disease outbreaks in response to the more acute, inter-annual, quasi-periodic ENSO (El Niño Southern Oscillation) cycle (1). The depletion of soil fertility and freshwater supplies, and the mismanagement of water catchment basins via excessive deforestation, also have contributed to the decline of various regional populations over the millennia (2).

Today, climate scientists predict that humankind's increasing emission of greenhouse gases will induce a long-term change in the world's climate. These gases comprise, principally, carbon dioxide (mostly from fossil fuel combustion and forest burning), plus various other heat-trapping gases such as methane (from irrigated agriculture, animal husbandry and oil extraction), nitrous oxide and various human-made halocarbons. Indeed, most climate scientists now suspect that the accumulation of these gases in the lower atmosphere has contributed to the strong recent uptrend in world average temperature. In its Third Assessment Report, published in 2001, the Intergovernmental Panel on Climate Change (IPCC) stated: "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (3).

During the twentieth century, world average surface temperature increased by approximately 0.6 °C (Figure 1.1). There were, of course, natural influences on world climate during this time. These include an increase in volcanic activity between 1960 and 1991 (when Mount Pinatubo erupted) which induced a net negative natural radiative forcing for the last two (up to possibly four) decades; and a slight overall increase in solar activity in the first half of the century which may have accounted for around one-sixth of that century's observed temperature increase. The twentieth century's global warming has taken Earth's average surface temperature above the centuries-long historical limit of the amplitude of natural variations.

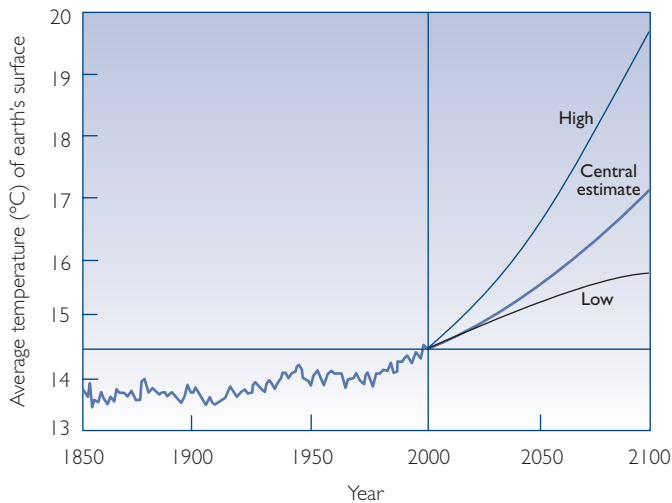


FIGURE 1.1 Global temperature record, since instrumental recording began in 1860, and projection for coming century, according to Intergovernmental Panel on Climate Change (3). The wide range around the projection reflects uncertainties about aspects of the climate system and future human economic activity and technology choices. World temperature has increased by around 0.4 °C since the 1970s and now exceeds the upper limit of natural (historical) variability. Climatologists consider around five-sixths of that recent increase to be due to human influence.

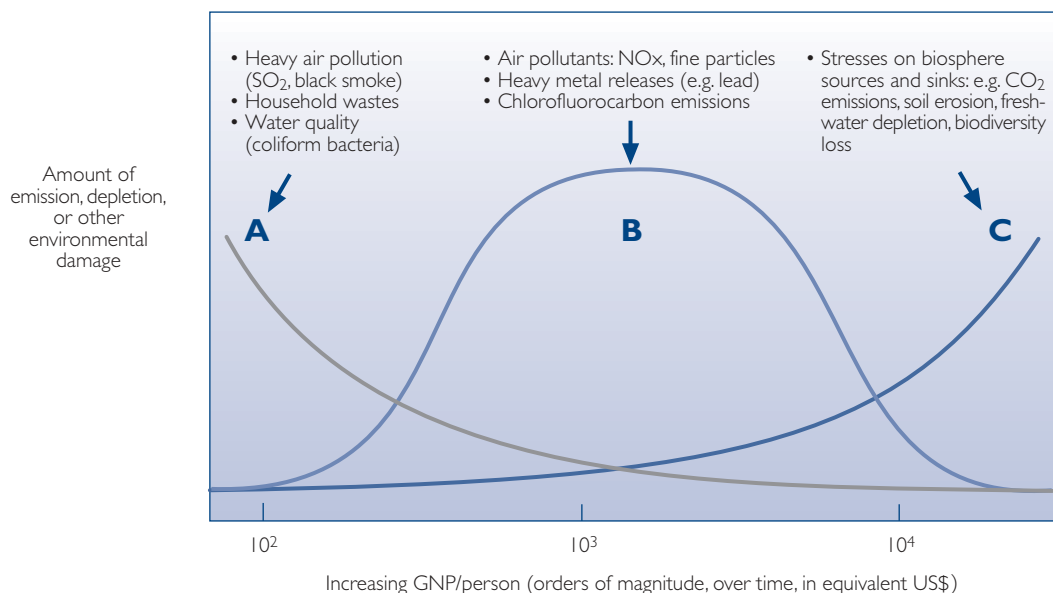
The unprecedented prospect of human-induced (rapid) changes to the global climate has prompted a large international scientific effort to assess the evidence. The IPCC, established within the UN framework in 1988, was charged with advising national governments on the causes and processes of climate change; likely impacts and their associated costs; and ways to lessen the impacts. The IPCC's Third Assessment Report (2001) projects an increase in average world surface temperature ranging from 1.4 to 5.8°C over the course of the twenty-first century (see Figure 1.1). That estimation, with its wide range, is drawn from a large number of different global climate models and a range of plausible scenarios of greenhouse gas and sulphate aerosol precursor emissions. Those scenarios entail different future storylines of demographic, economic, political and technological change. A temperature increase anywhere within this range would be much more rapid than any naturally occurring increase that has been experienced by humans since the advent of agriculture, around 10 000 years ago.

Recognising the complexity of systems upon which life depends: an ecological perspective

As a human-generated and worldwide process, global climate change is a qualitatively distinct and very significant addition to the spectrum of environmental health hazards encountered by humankind. Historically, environmental health concerns have focused on toxicological or microbiological risks to health from local exposures. However, the scale of environmental health problems is increasing and various larger-scale environmental hazards to human population health have begun to appear.

Appreciation of this scale and type of influence on human health entails an *ecological* perspective. This perspective recognises that the foundations of long-term good health in populations reside in the continued stability and functioning of the biosphere's life-supporting ecological and physical systems. It also brings an appreciation of the complexity of the systems upon which we depend and moves beyond a simplistic, mechanistic, model of environmental health risks to human health.

FIGURE 1.2 Diagrammatic representation of the typical sequence of three categories of environmental impacts and hazards to health resulting from human social and economic development. As a society becomes wealthier, more literate and better able to exert legislative control, the profile of local and community-wide environmental hazards (categories A and B) is reduced. Meanwhile, however, as the ecological footprint of the population increases, so larger scale and less locally evident environmental changes (category C) accrue.



In simplified diagrammatic fashion, Figure 1.2 illustrates the approximate chronological succession of environmental hazards, as societies undergo economic growth and consequent increases in the scale of human activity and environmental impact (4). Historically, on a local scale, category A hazards have predominated. In the early years of the industrial revolution in Europe much of the environmental hazard was at household and neighbourhood level. In the middle decades of the twentieth century developed countries began to reduce the levels of category B hazards, often via environmental legislation—such as the clean air acts of European and North American countries.

Today, category C hazards are increasing, reflecting the great pressures that human societies collectively exert on the biogeophysical systems of this planet. Carbon dioxide emission is an important example of a category C hazard. Emission rates increased markedly (around twelve-fold) during the twentieth century, as worldwide industrialization proceeded and land-use patterns changed at an accelerating rate.

The scale of environmental health problems has expanded from household (e.g. indoor air pollution) to neighbourhood (domestic refuse) to community (urban air pollution) to regional (acid rain) to global level (climate change). This requires consideration of the “ecological footprint” and how to curtail its size within the limits of global ecological sustainability. Folke and colleagues have estimated that the cities around the Baltic Sea require an area of land and sea surface several hundred times larger than the sum of the areas of the cities themselves (5). This large ecological footprint, typical of modern industrialized societies, comprises the supplies of food, water and raw materials and the

environmental “sinks” into which urban-industrial metabolic waste is emptied. The moral dilemma is clear: a world of six billion cannot live at that privileged level of environmental impact. There simply is not enough world available! A recent study has estimated that human demands on the biosphere have exceeded the world’s “biocapacity” since the 1970s, and is currently about 25% beyond the sustainable capacity of Earth (6).

Further, not only can the actions of one population affect the health of distant populations—as with the environmental dissemination of chlorinated hydrocarbons (persistent organic pollutants: POPs)—but actions today may jeopardise the well-being and health of future generations. There is already in motion a process of sea level rise that will continue for many centuries as the extra heat trapped at Earth’s surface by the human-amplified greenhouse effect progressively enters the deep ocean water. Similarly, it is likely that the continuing rapid extinction of populations and species of plants and animals will leave a biotically impoverished, less ecologically resilient and less productive world for future generations.

Despite global climate change currently being the most widely discussed of various recent global environmental changes, there is mounting evidence that humans, in aggregate, are overloading the planet’s great biogeochemical systems. This has been well summarised by Vitousek and colleagues:

“Human alteration of Earth is substantial and growing. Between one-third and one-half of the land surface has been transformed by human action; the carbon dioxide concentration in the atmosphere has increased by nearly 30% since the beginning of the Industrial Revolution; more atmospheric nitrogen is fixed by humanity than by all natural terrestrial sources combined; more than half of all accessible surface fresh water is put to use by humanity; and about one-quarter of the bird species on Earth have been driven to extinction. By these and other standards, it is clear that we live on a human-dominated planet.” (7)

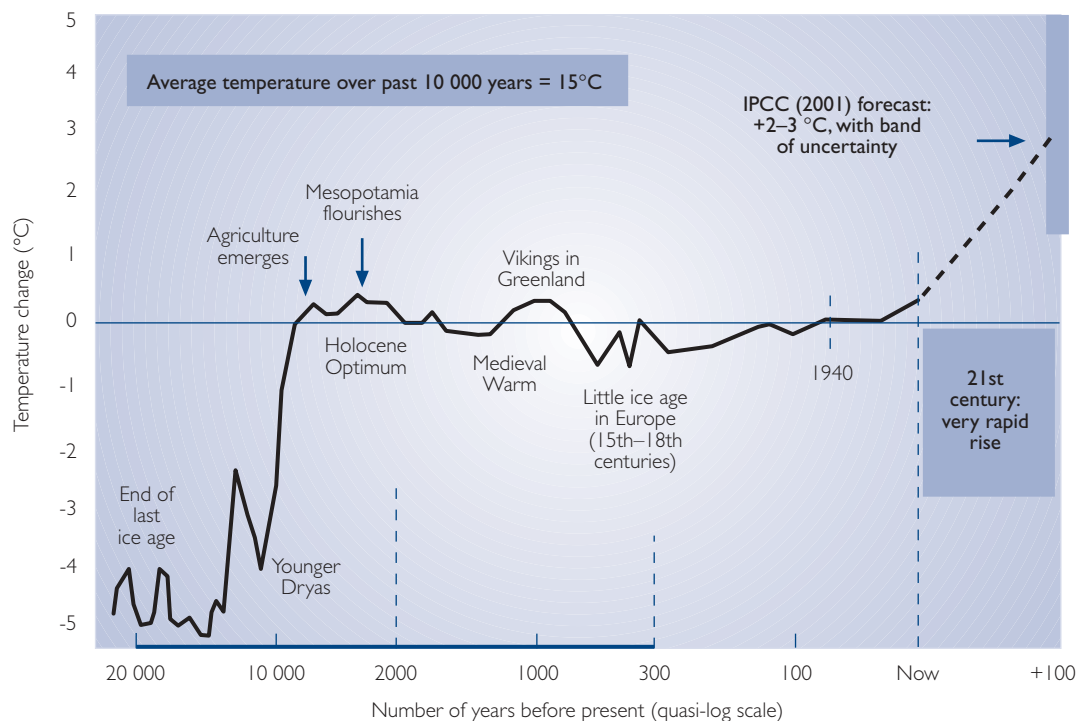
The long history of climatic fluctuations since the end of the last global glaciation around 15 000 years ago, along with the evidence of recent temperature rises and the IPCC’s projected rapid warming in the current century, are summarized in Figure 1.3. Several of the rises and falls of great civilisations are shown. Note that the climatic variations before around 1850 essentially were due to natural forcing processes—cosmological alignments, volcanic activity, solar activity and so on. Since 1850 there has been an increasing influence via human emission of greenhouse gases in excess of the biosphere’s capacity to absorb them without an increase in atmospheric concentration. That more recent period also is shown, in more detail, in Figure 1.1 above.

Climate change: overview of recent scientific assessments

The latest report from the Intergovernmental Panel on Climate Change (IPCC) makes several compellingly clear points (8). First, human-induced warming has apparently begun: the particular pattern of temperature increase over the past quarter-century has fingerprints that indicate a substantial contribution from the build-up of greenhouse gases due to human activities. Second, a coherent pattern of changes in simple physical and biological systems has become apparent across all continents—the retreat of glaciers, melting of sea ice, thawing of permafrost, earlier egg-laying by birds, polewards extension of insect and plant species, earlier flowering of plants and so on. Third, the anticipated average surface-temperature rise this century, within the range of 1.4 to 5.8°C, would be a faster

FIGURE I.3 Variations in Earth’s average surface temperature, over the past 20000 years.

Prior to 1860, analogue measures of temperature are necessary (tree rings, oxygen isotope ratios in ice cores and lake sediments, etc.). Note the substantial natural fluctuations throughout the period. Note also that (with the logarithmic nature of the time axis) the anticipated rate of increase in world temperature this century is 20–30 times faster than occurred as the planet emerged from the last glaciation, from around 15000 years ago.



increase than predicted in the IPCC’s previous major report, in 1996 (9). It is the rate of change in temperature that will pose a particular stress upon many ecosystems and species. The IPCC also reported that even if humankind manages to curb excess greenhouse gas emissions within the next half-century, the world’s oceans will continue to rise for up to 1000 years, reflecting the great inertial processes as heat is transferred from surface to deep water (10). By that time the sea level rise would have approximated 1–2 metres.

The estimated rise in average world temperature over the coming century conceals various important details. Anticipated surface temperature increases would be greater at higher latitudes, greater on land than at sea, and would affect the daily minimum night-time temperatures more than daily maximum temperatures. Alaska, northern Canada and northern Siberia, for example, could warm by approximately 5°C during the twenty-first century. Indeed, the temperature increases that have occurred already above the Arctic Circle have disrupted polar bear feeding and breeding, the annual migrations of caribou and the network of telephone poles in Alaska (previously anchored in ice-like permafrost). Global climate change also would cause rainfall patterns to change with increases over the oceans but a reduction over much of the land surface—especially in various low to medium latitude mid-continental regions (central Spain, the US midwest, the Sahel, Amazonia) and in already arid areas in north-west India, the Middle East, northern Africa and parts of central America. Rainfall events would tend

to intensify with more frequent extreme events increasing the likelihood of flooding and droughts. Regional weather systems, including the great south-west Asian monsoon, could undergo latitudinal shift.

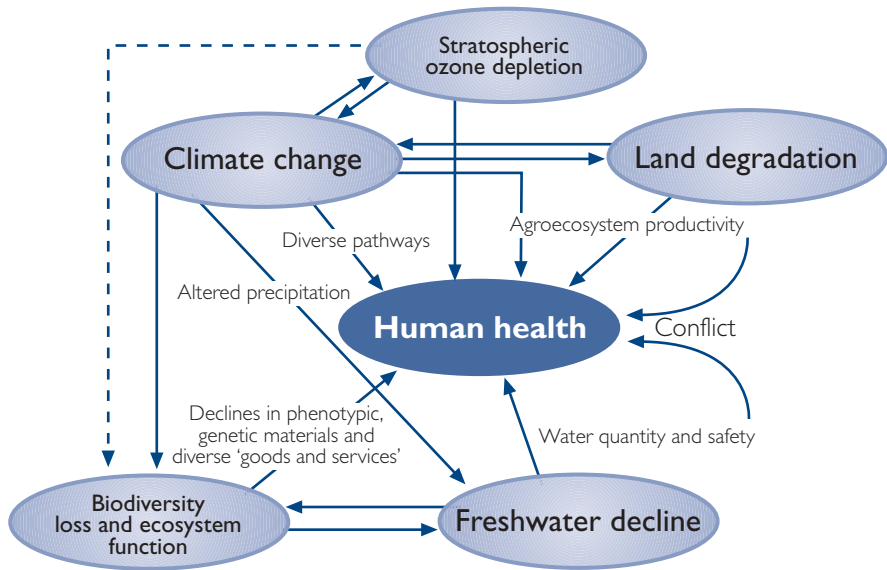
According to glaciologists there is a slight possibility that large sections of the Antarctic ice mass would melt, thus raising sea level by several metres. However, it appears that disintegration did not occur during the warm peak of the last interglacial period around 120 000 years ago, when temperatures were 1–2 °C higher than now. Nevertheless, substantial melting of Antarctic ice appears to have occurred in a previous interglacial, and several large ice-shelves have disintegrated in the past two decades (3). Another possibility is that the northern Atlantic Gulf Stream might weaken and eventually even shut down if increased melt-water from Greenland disturbs the dynamics of that section of the great, slow and tortuous “conveyor belt” circulation that distributes Pacific-equatorial warm water around the world’s oceans (3). North-west Europe, relative to same-latitude Newfoundland, currently enjoys 5–7 °C of free heating from this heat-source. If weakening of the Gulf Stream does occur over the coming century or two, Europe may actually become a little colder even as the rest of the world warms.

As mentioned earlier in this chapter, global climate change is only one of a larger set of destabilising large-scale environmental changes that are now underway, each of them reflecting the increasing human domination of the ecosphere (3, 11). These include major global changes such as stratospheric ozone depletion, biodiversity loss, worldwide land degradation, freshwater depletion, and others such as the disruption of the elemental cycles of nitrogen and sulphur, and the global dissemination of persistent organic pollutants. All have great consequences for the sustainability of ecological systems: food production; human economic activities and human population health (12). Figure 1.4 illustrates (in simplified fashion) how part of this complex of interacting, large-scale environmental changes impinges on human health. Many of the pathways would of course be modulated by cultural and technological characteristics of human societies. That is, local populations vary in their vulnerability to these potential impacts.

There is growing realization that the sustainability of population health must be a central consideration in the public discourse on how human societies can make the transition to sustainable development (13, 14). Hence, public, policy-makers and other scientists have an increasing interest in hearing from population health researchers, moving towards a view of population health as an ecological entity: an index of the success of longer-term management of social and natural environments (15). Indeed this recognition will assist in altering social and economic practices and priorities, to avert or minimize the occurrence of global environmental changes and their adverse impacts.

Change in world climate would influence the functioning of many ecosystems and the biological health of plants and creatures. Likewise, there would be health impacts on human populations, some of which would be beneficial. For example, milder winters would reduce the seasonal winter-time peak in deaths that occurs in temperate countries, while in currently hot regions a further increase in temperatures might reduce the viability of disease-transmitting mosquito populations. Overall, scientists consider that most of the health impacts of climate change would be adverse (16, 17). This assessment will be greatly enhanced by the accrual of actual evidence of early health impacts which epidemiologists anticipate will emerge over the coming decade.

FIGURE 1.4 Interrelationships between major types of global environmental change, including climate change. Note that all impinge on human health and—though not shown here explicitly—there are various interactive effects between jointly acting environmental stresses. The diverse pathways by which climate change affects health are the subjects of much of the remainder of this volume.



In the meantime, it is instructive to look back over the centuries and begin to understand how climatic changes and events can affect human well-being and health. This is a long and continuing story.

Climate and human health: an ancient struggle

Whoever wishes to investigate medicine properly, should proceed thus: in the first place to consider the seasons of the year, and what effects each of them produces, for they are not all alike, but differ much from themselves in regard to their changes.

Hippocrates, in Airs, Waters, and Places (18)

Recognition that human health can be affected by a wide range of ecological disruptions, consequent upon climate change, is a recent development, reflecting the breadth and sophistication of modern scientific knowledge. Nevertheless, the simpler idea that human health and disease are linked to climate probably predates written history.

The Greek physician Hippocrates (about 400 BC) related epidemics to seasonal weather changes, writing that physicians should have “due regard to the seasons of the year, and the diseases which they produce, and to the states of the wind peculiar to each country and the qualities of its waters” (18). He exhorts them to take note of “the waters which people use, whether they be marshy and soft, or hard and running from elevated and rocky situations, and then if saltish and unfit for cooking,” and to observe “the localities of towns, and of the surrounding country, whether they are low or high, hot or cold, wet or dry . . . and of the diet and regimen of the inhabitants”.

Two thousand years later, Robert Plot, Secretary to the newly-founded Royal Society in England, took weather observations in 1683–84 and noted that if the same observations were made “in many foreign and remote parts at the same time” we would “probably in time thereby learn to be forewarned certainly of divers emergencies (such as heats, colds, deaths, plagues, and other epidemical distempers)”.

Between these times, countless climatic disasters befell communities and populations around the world, leading variously to starvation, infectious disease, social collapse and the disappearance of whole populations. One such is the mysterious demise of the Viking settlements in Greenland in the fourteenth and fifteenth centuries, as temperatures in and around Europe began to fall. Established during the Medieval Warm Period during the tenth century AD (see Figure 1.3), these culturally conservative, livestock dependent, settlements could not cope with the progressive deterioration in climate that occurred from the late Middle Ages. Food production declined and food importation became more difficult as sea ice persisted. To compound matters, the native Inuit population in Greenland was pressing southwards, probably in response to the ongoing climate change. The Viking settlements eventually died out or were abandoned in the fourteenth (Western Settlement) and fifteenth centuries (Eastern Settlement) (19).

Historical accounts abound of acute famine episodes occurring in response to climatic fluctuations. Throughout pre-industrial Europe, diets were marginal over many centuries; the mass of people survived on monotonous diets of vegetables, grain gruel and bread. A particularly dramatic example in Europe was the great medieval famine of 1315–17. Climatic conditions were deteriorating and the cold and soggy conditions led to widespread crop failures, food price rises, hunger and death. Social unrest increased, robberies multiplied and bands of desperate peasants swarmed over the countryside. Reports of cannibalism abounded from Ireland to the Baltic. Animal diseases proliferated, contributing to the die-off of over half the sheep and oxen in Europe. This tumultuous event and the Black Death which followed thirty years later, are deemed to have contributed to the weakening and dissolution of feudalism in Europe.

Over these and the ensuing centuries, average daily intakes were less than 2000 calories, falling to around 1800 calories in the poorer regions of Europe. This permanent state of dietary insufficiency led to widespread malnutrition, susceptibility to infectious disease and low life expectancy. The superimposed frequent famines inevitably culled the populations, often drastically. In Tuscany, between the fourteenth and eighteenth centuries there were over 100 years of recorded famine. Meanwhile in China, where the mass rural diet of vegetables and rice accounted for an estimated 98% of caloric intake, between 108 BC and 1910 AD there were famines that involved at least one province in over 90% of years (20).

Food shortages are never due to climate extremes alone; the risk of famine depends also on many social and political factors. For example, a strong El Niño event in 1877 caused failure of the monsoon rains in south and central India (21). However, the intense famine that resulted, which caused somewhere between 6 and 10 million deaths, was only partly due to the drought. There was no shortage of food in India at this time (grain exports to the United Kingdom of Great Britain and Ireland reached an all time high in 1877), but a large proportion of the Indian population was unable to access food reserves, or to find alternative sources when their usual crops failed. There were many reasons for this. Under the British Raj, common lands that previously provided sustenance

in times of hardship had been converted to (taxable) private property. Local economies had been impoverished by punitive tariff schemes that favoured imported United Kingdom goods over local products. Aided by the expansion of the railways, community-controlled reserves of food had been replaced by remote stockpiles but there were no moral or regulatory controls over speculation. Because of these and other factors at the end of the nineteenth century many people in India were more vulnerable to adverse effects of drought than ever before.

In the light of this varied (often dramatic) history of the climate-society relationship, it is not surprising that scientists foresee a range of health impacts of a change in global climatic conditions. These will be explored in detail later in this volume. However, the following overview of the potential health impacts of climate change will orient the reader to that later assessment.

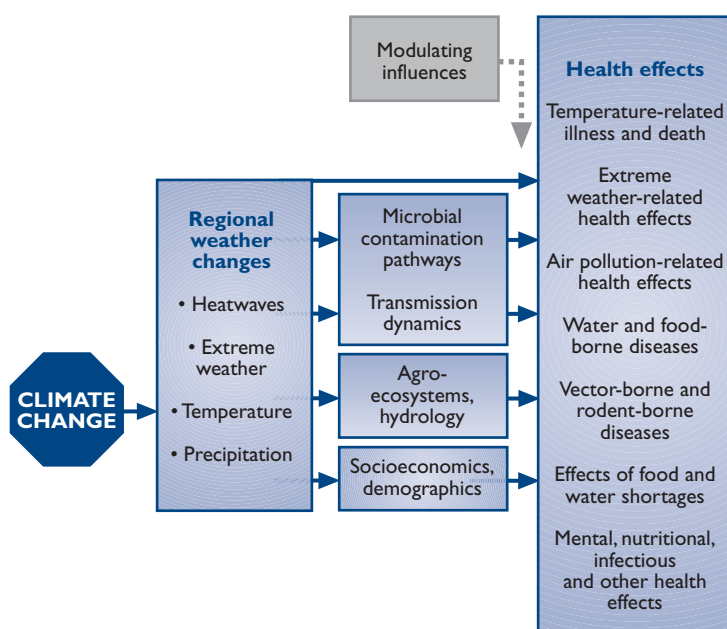
Potential health impacts of climate change

Global climate change would affect human health via pathways of varying complexity, scale and directness and with different timing. Similarly, impacts would vary geographically as a function both of environment and topography and of the vulnerability of the local population. Impacts would be both positive and negative (although expert scientific reviews anticipate predominantly negative). This is no surprise since climatic change would disrupt or otherwise alter a large range of natural ecological and physical systems that are an integral part of Earth's life-support system. Via climate change humans are contributing to a change in the conditions of life on Earth.

The main pathways and categories of health impact of climate change are shown in Figure 1.5.

FIGURE 1.5 Pathways by which climate change affects human health, including local modulating influences and the feedback influence of adaptation measures.

Source: adapted from Patz et al., 2000 (22).



The more direct impacts on health include those due to changes in exposure to weather extremes (heatwaves, winter cold); increases in other extreme weather events (floods, cyclones, storm-surges, droughts); and increased production of certain air pollutants and aeroallergens (spores and moulds). Decreases in winter mortality due to milder winters may compensate for increases in summer mortality due to the increased frequency of heatwaves. In countries with a high level of excess winter mortality, such as the United Kingdom, the beneficial impact may outweigh the detrimental (23, 24). The extent of change in the frequency, intensity and location of extreme weather events due to climate change remains uncertain.

Climate change, acting via less direct mechanisms, would affect the transmission of many infectious diseases (especially water, food and vector-borne diseases) and regional food productivity (especially cereal grains). In the longer term and with considerable variation between populations as a function of geography and vulnerability, these indirect impacts are likely to have greater magnitude than the more direct (25, 26).

For vector-borne infections, the distribution and abundance of vector organisms and intermediate hosts are affected by various physical (temperature, precipitation, humidity, surface water and wind) and biotic factors (vegetation, host species, predators, competitors, parasites and human interventions). Various integrated modelling studies have forecast that an increase in ambient temperature would cause, worldwide, net increases in the geographical distribution of particular vector organisms (e.g. malarial mosquitoes) although some localised decreases also might occur. Further, temperature related changes in the life-cycle dynamics of both the vector species and the pathogenic organisms (flukes, protozoa, bacteria and viruses) would increase the potential transmission of many vector-borne diseases such as malaria (mosquito), dengue fever (mosquito) and leishmaniasis (sand-fly)—although schistosomiasis (water-snail) may undergo a net decrease in response to climate change (27, 28).

Recently, there has been considerable effort in developing mathematical models for making such projections. The models in current use have well recognised limitations—but have provided an important start. For example, from computer multiple modelling studies it seems likely that malaria will significantly extend its geographical range of *potential* transmission and its seasonality during the twenty-first century as average temperatures rise (29).

Allowing for future trends in trade and economic development, modelling studies have been used to estimate the impacts of climate change upon cereal grain yields (which account for two-thirds of world food energy). Globally, a slight downturn appears likely but this would be greater in already food-insecure regions in south Asia, parts of Africa and central America. Such downturns would increase the number of malnourished people by several tens of millions in the world at large—that is, by at least several per cent against a current and projected total, without climate change, of between four and eight hundred million.

By reflecting the increased retention of heat energy in the lower atmosphere, global warming also affects the atmospheric heat budget so as to increase the cooling of the stratosphere (30). Should this cooling persist, the process of ozone depletion could continue even after chlorine and bromine loading (by human emission of ozone-destroying gases) starts to decline. If so, the potential health consequences of stratospheric ozone depletion (increase in incidence of skin cancer in fair-skinned populations; eye lesions such as cataracts; and,

perhaps, suppression of immune activity) would become an issue for climate change.

It is likely that climatic change over the past quarter-century has had various incremental impacts on at least some health outcomes. However, the time at which any such health impacts of climate change first become detectable particularly depends upon, firstly, the sensitivity of response (how steep is the rate of increase) and, secondly, whether there is a threshold that results in a “step function”. Further, detectability is influenced by the availability of high-quality data and the extent of background variability in the health-related variable under investigation. Detection is a matter of both statistical power and reasonable judgement about attribution. The former depends on numbers of observations and the extent of divergence between observed and expected rates or magnitudes of health outcomes. The latter includes pattern recognition: if a particular infectious disease undergoes changes in occurrence in multiple geographical locations, each in association with local changes in climate, it is more certain to be due to climatic influence than if such a change occurs in just one setting.

The first detectable changes in human health may well be alterations in the geographical range (latitude and altitude) and seasonality of certain vector-borne infectious diseases. Summertime food-borne infections (e.g. salmonellosis) may show longer-lasting annual peaks. There has been debate, as yet unresolved, over whether recent increases of malaria and dengue in highland regions around the world may be due to climate factors or to the several other factors that are known to be significant determinants of transmission. There are several other categories of likely early impact. Hot weather would amplify the production of noxious photochemical smog in urban areas and warmer summers would increase the incidence of food poisoning. By contrast, the public health consequences of the disturbance of natural and managed food-producing ecosystems, rising sea levels and population displacement for reasons of physical hazard, land loss, economic disruption and civil strife, may not become evident for several decades.

Population vulnerability and adaptive responses

Human populations, as with individuals, vary in their vulnerability to certain health outcomes. A population’s vulnerability is a joint function of, first, the extent to which a particular health outcome is sensitive to climate change and, second, the population’s capacity to adapt to new climatic conditions. The vulnerability of a population depends on factors such as population density, level of economic development, food availability, income level and distribution, local environmental conditions, pre-existing health status and the quality and availability of public health care (32).

Adaptation refers to actions taken to lessen the impact of (anticipated) climate change. There is a hierarchy of control strategies that can help to protect population health. These strategies are categorised as: administrative or legislative, engineering, personal-behavioural. Legislative or regulatory action can be taken by government, requiring compliance by all or designated classes of persons. Alternatively, adaptive action may be encouraged on a voluntary basis, via advocacy, education or economic incentives. The former type of action would normally be taken at a supranational, national or community level; the latter would range from supranational to individual levels. Adaptation strategies will be either reactive, in response to climate impacts, or anticipatory, in order to reduce

BOX 1.1 Health impacts of other types of global environmental change

Global climate change is part of a larger set of global environmental changes. As shown in Figure 1.4, these changes influence one another and often exert interactive impacts when acting in concert.

Stratospheric ozone depletion

Depletion of stratospheric ozone by human-made gases such as chlorofluorocarbons has been occurring over recent decades and is likely to peak around 2020. Ambient ground-level ultraviolet irradiation is estimated to have increased consequently by up to 10% at mid-to-high latitudes over the past two decades. Scenario-based modelling that integrates the processes of emissions accrual, ozone destruction, UVR flux and cancer induction, indicates that European and United States' populations will experience 5–10% excess in skin cancer incidence during the middle decades of the twenty-first century. If climate change and consequent stratospheric cooling delay the recovery of protective ozone, there will be greater numbers of excess skin cancers.

Biodiversity loss and invasive species

Increasing human demand for space, materials and food leads to increasingly rapid extinction of populations and species of plants and animals. An important consequence for humans is the disruption of ecosystems that provide “nature’s goods and services”. Biodiversity loss also means the loss, before discovery, of many natural chemicals and genes, others of which have conferred enormous medical and health improvement benefits. Myers estimates that five-sixths of tropical vegetative nature’s medicinal goods have yet to be recruited for human benefit (31).

Meanwhile, “invasive” species are spreading worldwide into new non-natural environments via intensified human food production, commerce and mobility. The resultant changes in regional species composition have myriad consequences for human health. For example: the choking spread of water hyacinth in eastern Africa’s Lake Victoria, introduced from Brazil as a decorative plant, is now a breeding ground for the water snail that transmits schistosomiasis and for the proliferation of diarrhoeal disease organisms.

Impairment of food-producing ecosystems

Increasing pressures of agricultural and livestock production are stressing the world’s arable lands and pastures. At the start of the twenty-first century an estimated one-third of the world’s previously productive land is seriously damaged: by erosion, compaction, salination, waterlogging and chemicals that destroy organic content. Similar pressures on the world’s ocean fisheries have left most of them severely depleted or stressed. Almost certainly an environmentally benign and socially acceptable way of using genetic engineering to increase food yields must be found in order to produce sufficient food for another three billion persons (with higher expectations) over the coming half century.

Allowing for future trends in trade and economic development, modelling studies have estimated that climate change would cause a slight downturn globally of around 2–4% in cereal grain yields (which represent two-thirds of world food energy). The estimated downturn in yield would be considerably greater in the food-insecure regions in South Asia, the Middle East, North Africa and Central America.

Other global environmental changes

Freshwater aquifers in all continents are being depleted of their ancient fossil water supplies. Agricultural and industrial demand amplified by population growth often greatly exceeds the rate of natural recharge. Water-related political and public health crises loom in some regions within decades.

Various semi-volatile organic chemicals (such as polychlorinated biphenyls) are now disseminated worldwide via a sequential distillation process in the cells of the lower atmosphere, thereby transferring chemicals from their usual origins in low to mid latitudes to high, indeed polar, latitudes. Consequently, increasingly high levels are occurring in polar mammals and fish and the traditional human groups that eat them. Clearly chemical pollution is no longer just an issue of local toxicity.

vulnerability. Adaptation can be undertaken at the international/national, community and individual level—that is, at macro, meso and micro-levels.

The reduction of socioeconomic vulnerability remains a priority. The poor (and especially the very young and old) are likely to be at greatest health risk because of their lack of access to material and information resources. Long-term reduction in health inequalities will require income redistribution, full employment, better housing and improved public health infrastructure. There must be improvement in services with a direct impact on health such as primary care, disease control, sanitation and disaster preparedness and relief. The vulnerability of the poor may jeopardise the well-being of more advantaged members of the same population. Examples of spillover effects include spread of infectious diseases from primary foci in poor populations and the opportunity cost of public services committed to dealing with problems related to disadvantage.

Improved environmental management of health-supporting ecosystems (e.g. freshwater resources, agricultural areas) would reduce the adverse health impacts of climate change. A good example is the control of water-borne infections. In many areas increased density of rainfall is likely to lead to more frequent occurrence of significant human infections such as giardiasis and cryptosporidiosis. Traditional public health interventions that focus entirely on personal hygiene and food safety have limited effectiveness. A broader approach would consider the interactions between climate, vegetation, agricultural practices and human activity—and would result in recommendations for the type, time and place of “upstream” public health interventions such as changes in management of water catchment areas.

The maintenance of national public health infrastructure is a crucial element in determining levels of vulnerability and adaptive capacity. The 1990s witnessed the resurgence of several major diseases once thought to have been controlled such as tuberculosis, diphtheria and sexually-transmitted diseases. The major causes were deteriorating public health infrastructure (especially the vaccination programme) as well as socioeconomic instability and population movement (33). Elementary adaptation to climate change can be facilitated by improved monitoring and surveillance systems. Basic indices of population health status (e.g. life expectancy) are available for most countries. However, disease (morbidity) surveillance varies widely depending on locality and the specific disease. To monitor disease incidence/prevalence—which may often provide a sensitive index of impact—low-cost data from primary care facilities could be collected in sentinel populations.

Such top-down approaches should be widely supplemented by adaptation at the community and individual levels. These would include local environmental management, urban design, public education, neighbourhood alert and assistance schemes, and individual behavioural changes. When implementing adaptation technologies care must be taken to prevent adverse secondary impacts (via maladaptation) that is, new health hazards created by the application of technologies. For example, conventional air-conditioning systems can increase the urban heat-island effect and might even exacerbate climate change itself. Water development projects can have significant effects on the local transmission of parasitic diseases including malaria, lymphatic filariasis and schistosomiasis.

Conclusions

Over the ages human societies have degraded or changed local ecosystems and modified regional climates. Without precedent, the aggregate human impact now

has attained a global scale, reflecting the recent rapid increase in population size and energy-intensive, high-throughput, mass consumption. The world population is encountering unfamiliar human-induced changes in the lower and middle atmospheres and worldwide depletion of various other natural systems (e.g. soil fertility, aquifers, ocean fisheries and biodiversity in general). Despite early recognition that such changes would affect economic activities, infrastructure and managed ecosystems, there has been less awareness that such large-scale environmental change would weaken the supports for healthy life. Fortunately that is now beginning to change. Indeed, this volume seeks to present a comprehensive discussion of the relationship between global climate change and human population health.

Global climate change is likely to change the frequency of extreme weather events: tropical cyclones may increase as sea surface waters warm; floods may increase as the hydrological cycle intensifies; and heatwaves may increase in mid-continental locations. As discussed in detail in later chapters, a change in the frequency and intensity of heatwaves and cold spells would affect seasonal patterns of morbidity and mortality. The production of various air pollutants and of allergenic spores and pollens would be affected by warmer and wetter conditions. Climate change also is expected to affect health via various indirect pathways, including the patterns of infectious diseases; the yield of food-producing systems on land and at sea; the availability of freshwater; and, by contributing to biodiversity loss, may destabilize and weaken the ecosystem services upon which human society depends.

Adaptations to the health hazard posed by global climate change can be both proactive and reactive, and can occur at the macro, meso and micro-scales; that is, at the population, community and individual levels. Climate change represents a one-off global experiment so there will be limited opportunity to carry out preliminary evaluation of adaptation options. There is therefore a strong case for prudence, both in mitigating climate change and in adapting to its impacts.

This topic is likely to become a major theme in population health research, social policy development and advocacy during this first decade of the twenty-first century. Indeed, consideration of global climatic-environmental hazards to human population health will play a central role in the sustainability transition debate.

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