Global Impacts of Anthropogenic Climate Change on Human Health and Adaptability

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INTRODUCTION

The earth has undergone natural processes of climate change since the beginning of life more than three billion years ago. And these natural processes of change continue during the present time. During the past 10,000 years of the present or Holocene Epoch, global conditions have been relatively warm but highly variable (Cohen, 2003: 367-8), whereas during the Pleistocene Epoch which preceded the Holocene (beginning at 1.8 million years ago), there were several dramatic periods of warming and cooling that led to major continental glacial advances and retreats (Overpeck et al., 2005). When modern humans began to evolve, some 100,000 to 200,000 years ago, their population numbers were small. Human population numbers began increasing about 10,000 years ago with the introduction of agriculture and nucleated village settlement, which coincided with the end of the Pleistocene Epoch. This population increase accelerated following the Age of European Exploration during the 16th and 17th centuries and the later Industrial Revolution about 250 years ago. This combination of human population expansion and increasing use of fossil fuels, associated with transportation, industry and manufacture, and high consumption of resources and production of wastes, has led to dramatic global changes, particularly anthropogenic climate change.

A very simple model of these processes illustrates the basic relationships leading to the current conditions of climate change and some effects of climate change that can influence human health and well being (see Fig. 1). Solar and terrestrial processes are enhanced or moderated by life forms on the earth to produce natural climate change. Global patterns can be influenced by tectonic activity (movement of tectonic plates and mountain building) changing terrestrial air movement and rainfall, leading, in turn, to vegetation growth, which will moderate solar albedo (earth reflectance). Other natural climate "forcings" (an imposed perturbation of Earth's energy balance; NRC, 2001: 6) include volcanic eruptions and fluctuations in energy flows from the sun.

Human-induced or anthropogenic climate change increases or reduces the effects of natural climate change by bringing a single life form into the equation. But humans, because of their vast numbers and technology, can have a potentially greater influence on climatic processes and climate forcing than other life forms. There is good evidence now that the increasing practice of burning fossil fuels and biomass (wood) and the transformation of the biosphere have led to accelerated climate change. Greenhouse gasses (GHGs) – CO_2, CH_4, N_2O, and halocarbons – lead to increased global temperatures, while chlorofluorocarbons (CFCs) contribute both to greenhouse gas temperature increases and to stratospheric ozone depletion (O'Neill, 2001: 4-10). As modernization and industrialization increase in developing nations around the world, these anthropogenic processes have an escalating effect on climate.

Global warming and ozone depletion have manifold cascading effects. *Global warming* leads to melting of ice from continental glaciers with consequent rise in oceanic sea level, loss of land surface area, dilution of the seas, changes and shifts in global weather patterns, and disruption of ecosystems leading to losses in biodiversity (Hannah et al., 2005). A major compilation of research by scientists from the Intergovernmental Panel on Climate Change (IPCC) has demonstrated beyond any reasonable doubt that human activities have produced a 0.6°C (1.1°F) rise in average global temperature over the past one-and-a-half centuries. And by the year 2100, this global temperature is expected to rise another 1.0 to 3.5°C (1.8 to 6.3°F), a change that is greater than any experienced on the globe within the past 10,000 years (Houghten et al., 2001: 2-5). Furthermore, climate models and simulations of "annual mean global surface temperatures" demonstrate that it is anthropogenic climate forcing or induced change and not natural processes that are contributing to global warming (Houghten et al., 2001: 11). Most recently, climate

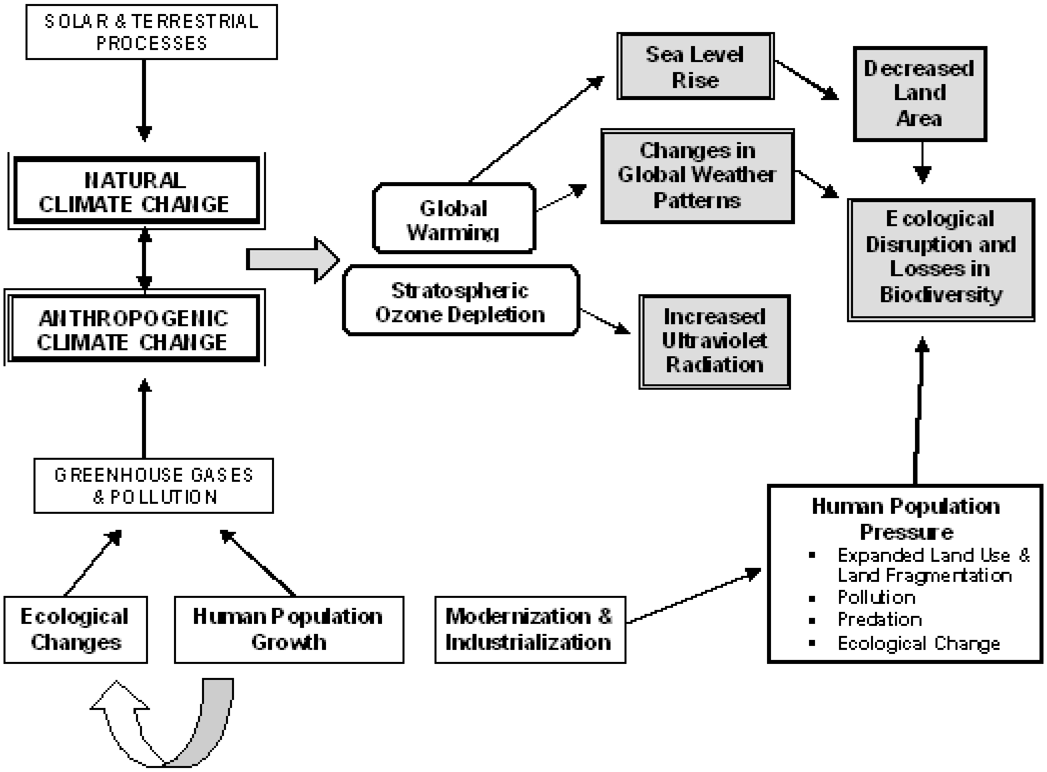

Fig. 1. A model illustrating some of the basic relationships among the parameters of climate change.

models indicate that anthropogenic forcings are producing a condition where the "…Earth is now absorbing 0.85 ± 0.15 watts per square meter more energy from the Sun than it is emitting to space" (Hansen et al., 2005: 1431). Hence, the earth is in a state of positive energy balance – it is gaining heat.

Ozone depletion allows greater amounts of ultraviolet (UV-B) radiation to pass through the stratosphere. UV radiation, among other influences, is damaging to life, can have an adverse effect on the growth of terrestrial plants, and impairs the production of marine phyto-plankton, which may limit the ocean in acting as a sink for CO_2 (further enhancing the greenhouse effect) (Martens, 1998: 3-4). The proximal effects of global warming and ozone depletion, such as sea level rise, decreased land area, global weather changes, ecological disruption, and elevated UV radiation, will ultimately impact human health and well being in a variety of ways. Some of these impacts can be explored in the context of human adaptation to changing environments with a view to the limits to adaptation that may be imposed in a rapidly changing environment.

HUMAN HEALTH AND ADAPTATION TO CLIMATE CHANGE

Humans are one of the most adaptable species on earth by virtue of their large brains, cognitive power, and complex behavior known as "culture." They are widespread throughout the globe, having reached their present geographical distribution about five centuries ago after the island Pacific was fully inhabited. As a result, humans have adapted to global climates on all of the continents that vary from Arctic, temperate seasonal, and mountain cold to tropical and seasonal temperate heat; from deserts to rainforests and tundra to Mediterranean scrub; and from periods of dramatic climate change to periods in which climate change has been slight or moderate. There are, however, limits to human adaptability in the short term that are a function of the severity of the environment and the very rates of environmental change (Baker, 1968; Little, 1997). In the context of human health, adaptation and adaptability can be defined as the ability to maintain a healthy lifestyle despite threats from the social and physical environment. Domains of adaptability in good health include: reproductive capacity, normal growth, adequate nutrition, ability to combat disease (immune sufficiency), capacity to perform work, and a secure emotional and rewarding intellectual life (Boydon, 1972; Mazess, 1978).

Human adaptations to changing environments have arisen through a combination of culture, social processes, biological plasticity, and genetic change. Genetic changes via Darwinian evolution, that is, by selection of favorable phenotypic attributes through fertility and mortality variations, are unlikely to contribute much toward human adaptation to anthropogenic climate change. The present climatic transformation of our globe is far too rapid for the slow process of natural selection to operate effectively. Any adaptability in humans is therefore likely to arise through behavioral and cultural changes, changes in social and political institutions, migration, or in biobehavioral plasticity (the ability to accommodate to environmental variation and environmental extremes). Identifying the limits of adaptability of human populations in the face of global climate change is one of the challenges we currently face.

GLOBAL WARMING

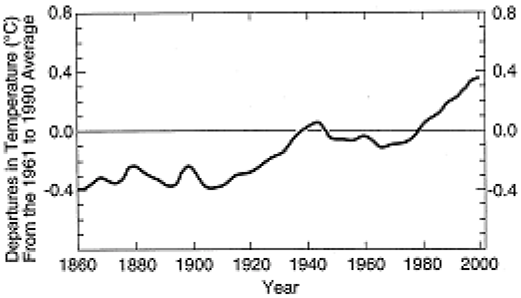

Fig. 2. The trend in mean global warming from 1860 to 2000 shown as departures in emperature (in °C) from the 1961to1990 average. (after Houghton et al., 2001: 26)

Figure 2 illustrates the trend in global temperatures over the past century and a half. These temperature increases have resulted from increased anthropogenic production of greenhouse gases that have exceeded the atmospheric “cleansing capacity” (Prinn, 2003) and the carbon dioxide (CO_2) uptake capacity of the seas. After remaining relatively constant at 280 parts per million (ppm) for 800 years, atmospheric CO_2 levels have increased to 360 ppm. Projected increases of CO_2 by the end of the 21st century are likely to reach between 540 and 970 ppm. Methane (CH_4) and nitrous oxide (N_2O) levels have shown corresponding increases, all beginning in the early 19th century (Houghten et al., 2001: 6, 12).

The patterns leading to warming are complex, indeed, with multiple feedbacks, where global averages do not reflect either seasonality or regional modes of variation that influence these global temperature changes (Wang and Schimel, 2003). For example, Figure 3 shows several model normal distributions of ambient temperatures with increases in the mean and in the variance. If the mean increases, then there is less cold weather and more warm weather (a). However if the variance in ambient temperatures increases without a change in the mean temperature, then both hot weather and cold weather will increase (b). If both the mean temperature and the variance increase, then there are likely to be record hot ambient temperatures (c) and associated weather anomalies, such as level 5 hurricanes and cyclones. For example, the Orissa cyclone of October 29, 1999 killed more than 10,000 people and made 10 million homeless. The August 29, 2005 hurricane that devastated the city of New Orleans was partly attributed to higher than normal water temperatures in the Gulf of Mexico.

Returning to Figure 2, the 0.6°C rise in average global temperature from the year 1860 to 2000, which is a clear anthropogenic trend, masks more dramatic increases in some regions and more extreme weather variations in others. For example, projected temperature changes to the year 2070 in Canada and the United States range from mid-latitude, temperate values of + 1 to + 3 ºC to high-latitude, arctic and sub-arctic values of + 3 to + 7 ºC (Flato et al., 2000). This continuing climatic temperature forcing has raised the energy balance of the earth to the extent that the decade between 1990 and 2000 was the warmest in the past 1000 years, and the projected average global rise of 1.0°C to 3.5°C during the 21st century will be an increase unmatched during the last 10,000 years (Houghten et al., 2001: 2-5).

Effects of these changes since the 1950s to 1970s are (Houghton et al., 2001: 2-12):

- Decrease in snow cover of about 10 percent in the Northern Hemisphere
- Retreat of mountain glaciers throughout the world
- Arctic sea-ice thickness has declined by about 40 percent
- Rise in sea level between 10 cm and 20 cm (4 in to 8 in) during the 20th century
- Precipitation has increased in some areas and decreased in other areas
- Heavy precipitation events have increased in mid-latitudes
- Reduction in frequency of extreme low temperature
- Recent (since 1970s) El Niño-Southern Oscillation (ENSO) events have been more frequent and intense than in the previous 100 years
- Increase in droughts in Africa and China in recent decades

Some of the characteristics of temperature and precipitation variation in the 21st century are likely to be the following (Houghton et al., 2001: 15-16):

- Higher maximum temperatures over nearly all land areas
- Higher minimum temperatures over nearly all land areas
- Reduced diurnal temperature range over most land areas
- Increase in heat index (heat stress) over land areas
- More intense precipitation events
- More variable precipitation (especially in summer monsoons)
- Increased summer continental drying in some areas

Other 21st century changes are likely to be (Houghton et al., 2001: 16):

- Continuation of retreat of glaciers and ice caps
- Global mean sea level will rise between 9 cm and 90 cm (3.5 in and 35 in)
- Snow cover and sea ice in Northern Hemisphere will continue to decrease

Even if greenhouse gases are stabilized sometime during the 21st century, the effects of climatic warming trends will continue for several hundred years because of the long timescales of ocean adjustment to temperature change. This includes glacial melting and sea level rise.

It is estimated that the impacts of global warming will be greatest in those regions of the world such as Asia, Africa, Latin America, and the Pacific Islands, where the adaptive capacity is low and vulnerability is high because of the lack of economic resources (McCarthy, 2001: 14-17). Africa and Central Asia are likely to be especially hard hit because such a large part of their land resources are arid or semi-arid steppe and savanna lands. Of the total desertification and degradation around the globe, nearly 30 percent is in Africa (Reilly et al., 2000). Overgrazing, overpopulation, and warming trends are some of the multiple causes of desertification; global warming will tend to increase the expanse of dry lands on this continent and elsewhere. In India, an already stressed system of fresh-water production will become further stressed with increased drying from climate change and continuing population gain (Cassen and Visaria, 1999). In fact, outside of the Developing World, mid-continental, temperate lands are most vulnerable to drought and high summer tempera-

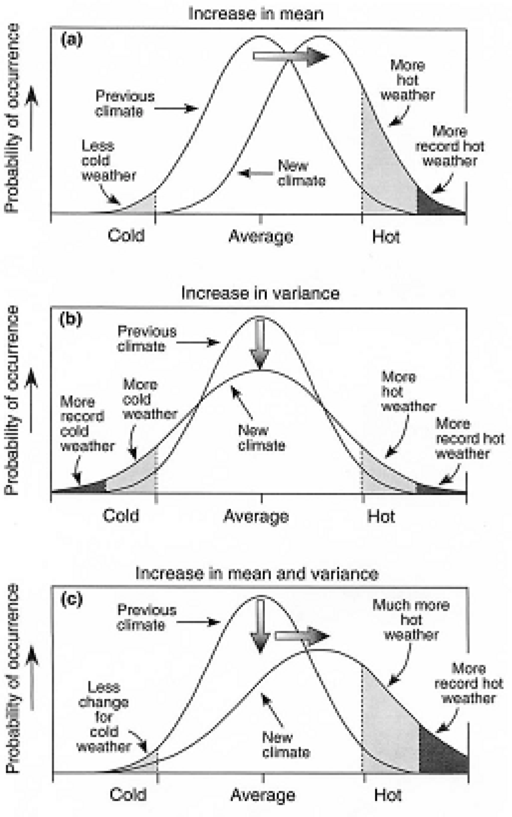

Fig. 3. Model temperature changes, where (a) there is an increase in the mean, (b) there is an increase in the variance, and (c) there is an increase in both the mean and the variance. (after Houghton et al. 2001: 155)

tures at present, and these will increase with global warming.

There are several categories of stress in humans that will be worsened under conditions of increasing global warming. These are: heat stress, nutritional stress, and disease stress, both chronic non-infectious and infectious disease.

Heat Stress

Environmental heat stress affecting humans is characteristically divided into hot-wet (high humidity) and hot-dry (low humidity) stress. Hot-wet conditions impose limits on evaporative cooling (sweating), whereas hot-dry conditions limits water resources. In the latter case, scarce water resources can lead to food shortages and hunger, as well. Bright sunlight, in combination with stratospheric ozone depletion (see below), can also enhance ultraviolet radiation exposure and consequent skin damage. Heat stress can lead to mortality through dehydration (heat exhaustion), total failure of the thermoregulatory system (heat stroke), or stress on the cardio-vascular system. Those most vulnerable are the very young, the elderly, and those required to do heavy physical work at high temperatures.

In areas of high humidity and seasonally-high hot temperatures, such as the southeastern and mid-continental United States, elevated temperatures will increase heat stress and lead to excess mortality from heat, especially in urban centers. Heat waves in urban centers over the past 50 years may be used as predictors of the likely effects of global warming in the future. An example of this is a heat wave that struck Chicago in July1995 leading to several hundred heat-related deaths (largely among the young and very old) (Chagnon et al., 1996). More recently, during the summer of 2003, Europe was struck by a disastrous heat wave that led to as many as 15,000 deaths in France by the end of August (King, 2004). The high mortality in France was a function of unprecedented extreme conditions with temperatures hovering between 35°C and 40°C for several days. There were no social, technical, or medical mechanisms in place to deal with such extreme temperatures. Kalkstein (1992) suggests that it is the abrupt warming or extreme heat waves in temperate zone cities and not persistent hot temperatures that exist in subtropical and tropical cities that leads to excessive heat-stress mortality. That is, it is not only a lack of heat acclimatization that proves to be highly stressful and leads to high levels of heat-related morbidity and mortality, but also a lack of preparedness for extreme heat. Accordingly, average global warming will have only a slight impact on heat related mortality. However, extreme weather conditions, which are likely to escalate with global warming, will have disastrous effects, and are likely to strike with increasingly higher temperatures and increasing frequency. Martens (1998: 124-125), in his survey of the effects of temperature extremes on cardio-vascular and respiratory mortality, suggested that the ameliorating effects of average global warming on cold-stress mortality is likely to balance out the effects of increased heat stress on mortality in humans.

There is also the issue of heat stress in domestic animals. Most livestock (pigs, sheep, cattle) in Western nations are adapted to temperate climatic zones, and are sensitive (particularly cattle) to high environmental temperatures and radiation. Body mass and coat color influence tolerance to heat, as does the digestive heat generated by ruminant animals. Livestock exposed to warm temperatures show, for example: decreased feeding and slower weight gain, slow growth rates to maturity, lower fertility, increased mortality in young animals, and lower milk production (Mount, 1979). Hence, temperate zone heat stress associated with global warming in livestock will initially reduce the food productivity of these animals in meat, milk, and other products.

Nutritional Stress

Global warming will impact human nutritional health via world and regional agricultural production, and also through the politics and economics of food production and distribution. Another important consideration is population growth, which places increasing demands on food productivity. The complexities of these variables make for an almost impossible modeling task at the global level other than for modeling the gross production of major grains. At continental and regional levels, some scenarios can be predicted by a systematic inspection of the specific effects of climate change on food production. Some of the important factors are: (1) temperature, (2) rainfall and water availability, (3) land availability, (4) soil properties, (4) CO_2 fertilization, and (5) extreme events (O'Neill et al., 2001: 144 ff.).

There is general agreement that climate change will move isotherms toward the poles, and that warming will be greater at high latitudes than in temperate or tropical belts. This shift in agricultural zones might benefit some regions, but other zones are likely to suffer from desiccation and reduced productivity. Another problem that is likely to result from climate warming is an increase in plant pests and diseases (Döös, 1994). The vulnerability of agricultural crops will increase as new insects and pathogens move into newly warm zones (Epstein, 2002). There is also a general consensus that climate warming will lead to water scarcity in dry areas that are already suffering from some degree of water stress (O'Neill et al., 2001: 158-160). These same areas are likely to be experiencing increased soil salinization from irrigation and depletion of aquifer reserves, where each condition will be aggravated by the warming process. Land availability for agriculture will decrease as sea level rises (along coastal areas, especially South and East Asia), and more arable land will be lost through drought, erosion, acidification, and other processes. There may be some new land made available for agriculture through continued deforestation and irrigation, but these remaining land resources are limited (Döös, 1994). On the positive side, increased atmospheric CO_2 levels that are projected to contribute further to global warming, also promote photosynthesis and plant growth, but the effects of this are not clear in light of future soil nutrient and water limitations (Döös, 1994). Finally extreme weather events, which are a reflection of climatic variability, are likely to increase with warming. Heat waves, storm surges, droughts, floods, and monsoon and El Niño fluctuations are likely to be more severe as the normal distribution of temperatures shifts to the right side of the curve.

All of these factors will influence agricultural production and the availability of food, both regionally and globally. Optimistic estimates of global production of primary staple grains from 1990-2025 indicate that grain production per capita will decrease (Döös, 1994). These estimates are based on projected declines in population growth, global warming trends, and modest improvements in agricultural productivity. The effects of global warming on human nutritional status and food security worldwide will be highly variable. Food producing nations and regions will be better off than Third World nations that must import food; areas in temperate zones will be better off than tropical zones where optimal temperatures for cultivation will be surpassed; and nations with stable political and economic systems will be better able to regulate food production and distribution than less stable nations (Woodward, 2002). With approximately 13 percent of today's world population already experiencing hunger, nutritional deficiency, and a lack of food security, global warming can be expected only to increase this percentage.

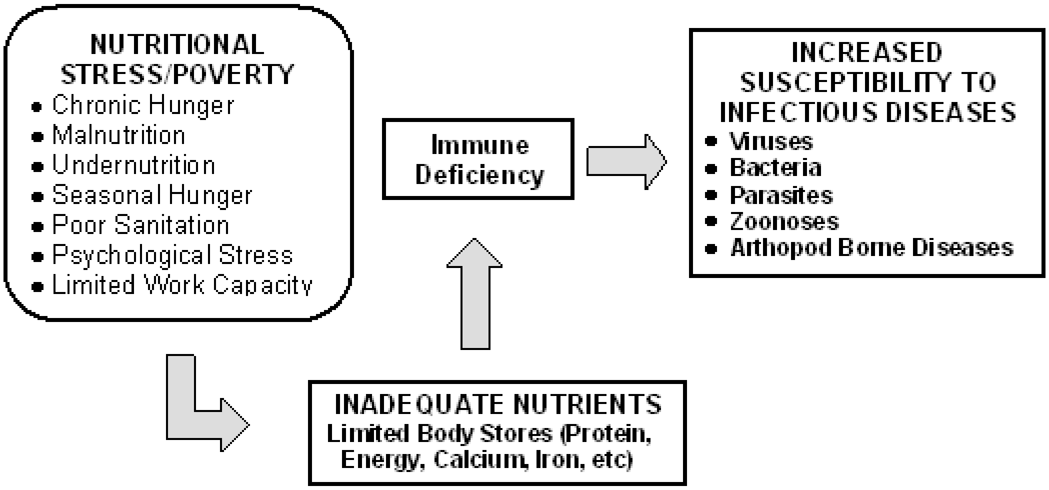

Fig. 4. The effects of nutritional stress and poverty on immune deficiency and susceptibility to infectious diseases.

Disease Stress

Infectious disease stress is intimately linked to nutritional stress in a variety of ways. Hence, negative influences of global warming on diet and nutritional status will ultimately affect disease, principally through susceptibility. Figure 4 illustrates some fundamental relationships. As already noted, global warming will have a greater negative impact on the Developing World whose adaptability to rapid climate change is limited. As nutritional stress and poverty increase with decreasing food production, the immune system is less capable of combating infection of all kinds and susceptibility increases (Martorell, 1980). It is generally the case that few members of impoverished populations actually die of hunger; rather, mortality is usually the result of disease that affects those weakened from states of chronic or acute poor nutrition.

In addition to the indirect effects of nutritional stress on infectious disease, another major impact of global warming will be changes in insect and other vectors of disease and the epidemiology of vector-borne diseases such as malaria (*Anopheles* mosquito), dengue fever (*Aedes* mosquito), Rocky Mountain spotted fever (hard tick), trypanosomiasis (tsetse fly), guinea worm (fresh-water copepod crustacean), schistosomiasis (fresh-water snail), and Chagas disease (triatomid bug), among others (O'Neill et al., 2001: 168; Epstein, 2002). Climate change can: (1) move new vectors or intermediate hosts into a geographic area; (2) produce a change in the vector or the infectious agent that makes humans more vulnerable; and (3) produce a change in human behavior that increases human susceptibility to an infectious agent (Martens, 1998: 28).

In the first case, most vector-borne diseases are found in warm temperate or tropical areas. Hence, global warming will extend the distribution of vector-borne diseases into previously cooler areas, many of which support very large human populations. Global warming can also allow insects to move into higher elevations, as is the case with mosquitoes. In the second case, climate change in geographic areas where insect and other vectors are normally found may stimulate increased vector or parasite populations through lengthened or shortened breeding cycles, decreased mortality, or increased density. For mosquitoes, increased rainfall and standing water in some areas will serve reproduction and mosquito larvae development. Alternatively, increased aridity from climate warming in other areas will reduce or eliminate some vectors. In the third case, human migration, development of drug resistance, reduced immune status, disrup-tion of sanitation facilities, or subtle changes in life style and behavior are all likely to increase human susceptibility to vector-borne diseases. Global climate change can shift some marginal areas from sporadic epidemic to endemic, and other areas from disease-free to epidemicity.

Epstein (2002) reviewed changes in vector-borne and other infectious diseases and how they respond to climate warming. He reported that warmer temperatures already have shifted isotherms toward higher latitudes and higher altitudes, with the distributions of mosquitoes and ticks following these isotherms. A good example is mosquito distribution by elevation in the tropics and sub-tropics. *Aedes aegypti* mosquitoes that carry dengue fever have moved upward more than 1,000 meters in the Colombian Andes, and dengue fever itself is now found in Mexico about 700 meters higher than in the past (Epstein et al., 1998). In West New Guinea, Indonesia, malaria can now be found at unprecedented elevations greater than 2,000 meters (Epstein et al., 1998). Insect vectors are particularly sensitive to the warmer minimum nighttime and warmer minimum winter tempera-tures that are occurring now in many temperate zones of the world. Epstein (2002) suggested that the geographic shifts in insect populations can be used as "fingerprints" for a process of global warming that has already contributed to ecological change on the planet.

Water-borne diseases are likely to increase in prevalence with global warming because of precipitation changes, contamination of fresh water supplies, and sea level intrusion into freshwater areas to limit fresh water reserves. Amoebiasis, cholera, giardia, shigellosis, and typhoid fever are a few of the many gastro-intestinal epidemic diseases that are transmitted by poor sanitation and contaminated water supplies (Webber, 1996). A case in point is the 1991 coastal Peru and South America cholera epidemic (CDC, 1991). The disease began in late January 1991 in Chancay and Chimbote and spread to other northern coastal Peruvian cities. It then reached other parts of coastal South America later in the year, and spread to the United States via airline and cruise ship passengers in

1992. This was the first 20th century cholera epidemic in South America. It is reported to have caused up to a million cases of cholera and 10,000 deaths (Mahon et al., 1996).

Cholera is caused by a bacterium (V*ibrio cholerae*) that releases a toxin in the intestine that produces a watery diarrhea leading to severe dehydration. Crude sewage and other water routes spread it, and it can survive in fresh water for several weeks and in mildly saline water (estuaries and lagoons) for up to a week (Webber, 1996). Untreated by oral or intravenous rehydration, the mortality may be as high as 50 percent. There are several biotypes of cholera, with the El Tor biotype producing the South American epidemic. Ewald (1994: 72 ff.) has shown that the cholera bacterium will become less virulent if sanitation and the water supply improve. This process also holds for Shigella species. Reduced virulence is a function of evolutionary change where restricted transmission of the microorganisms (water route) selects for a milder variety, since transmission must be by another route, as with an ambulatory host. As global warming produces a rise in sea level and salt water infiltrates estuaries, human populations will be forced to become even more concentrated along coastal regions. At the same time, their increasing dependence on fresh, clean water supplies will lead to scarcity of this vital resource. This is an ideal scenario for cholera and other water-born epidemics to arise, as the infrastructure for water purification and delivery and waste disposal is stressed.

Migration and Health

Population numbers in a given geographic area can be changed in only three ways: through births, deaths, or movement in or out of the area. Movement in or out – migration – is the "time honored" way that people have employed to avoid undesirable conditions (emigration) and to seek more favorable conditions (immigration) (Little and Baker, 1988). The degree and pattern of international migration in the future will be a function of population growth in lesser-developed nations and the effects of global warming on food production and its distribution. There are a number of global population trends that will influence population displacement and migration in the context of climate warming: (1) the world population will probably increase by several billion before leveling off or decreasing numerically; (2) the population of lesser-developed nations (those less adaptable to climate change) is increasing at a greater rate than in the more-developed nations; (3) this leads to an increasing numerical and economic disparity between lesser- and more-developed nations; (4) because of worldwide fertility declines the human population is aging and dependency ratios (younger productive/older less productive) are declining; and (5) the world's population is becoming more urbanized, with cities growing at alarming rates (O'Neill et al., 2001: 76). Each of these population trends will be impacted by global warming through heat stress (in proliferating urban centers and temperate zone heat waves), nutritional stress (as food production for increasing numbers is disrupted), and disease stress (as vector-borne diseases are transmitted to densely populated areas, and susceptible, aging humans are increasingly infected). Migration and rapid population movement (e.g., airline travel) brings not only people and their cultures, but it brings people as carriers of infectious diseases, some of them newly emerging with little control over their spread.

As populations in lesser-developed parts of the globe experience enhanced pressure on resources, and as global warming disrupts expected climatic patterns, there are likely to be agricultural declines for several reasons. Ground water levels will fall as below-ground reserves are depleted or not recharged, salinization will increase with increased sunshine, and desertification is likely to occur with other kinds of environmental degradation. hese patterns of environmental degradation will increase poverty, which is a root cause of much migration (OSCE, 2005). The concept of "environmental refugees" or "environmental migrants" has been used to identify groups of people who have left a geographic area because of reduced food productivity and impoverishment. Such patterns of migration are expected to increase as the effects of global warming begin to be felt, and these movements of people will be from the Southern Hemisphere, where most lesser-developed peoples reside, to the Northern Hemisphere (O'Neill et al., 2001: 177). Since there are social, political, and economic impacts of emigrants on the host or receiving nation, there are likely to be policy responses that may limit emigration by the Western nations. As O'Neill et al. (2001: 176) state: "The response to global environmental change in a world with relatively free international movement of labor (and capital) is bound to be very different from the response in a world with closed borders."

Zlotnik (1996) estimated an annual international migration rate of 4.35 million migrants/year from the lesser developed world to the more developed world. Some of these are probably return or transient migrants and it would be difficult to classify them as strictly environ-mental migrants. However, it is likely that the pressures of population growth in lesser-deve-loped regions and climate change will lead to an increase in these migratory numbers, and such patterns of migration may lead to international conflict.

CHANGES IN GLOBAL WEATHER PATTERNS AND CLIMATIC EXTREMES

Global warming is superimposed on normal climatic variation that includes extreme events leading to droughts, floods, heat waves, cold periods, excessive wind flow (tornados, hurricanes), storm surges, and lightning storms. All of these can be destructive, leading to loss of human lives and property. Some extreme events can produce permanent changes in the landscape that can influence human habitation and subsistence. As noted, a shift toward warmer global temperatures has already produced more extreme precipitation events and droughts, especially in the temperate and high latitude Northern Hemisphere (Houghton et al., 2001: 103-104,153). Despite the extremes in precipitation events associated with other global warming patterns, there is no evidence that storm surges have increased in frequency or intensity nor have wave heights increased in size over the past century (Houghton et al., 2001: 664).

The impact of climate change on human population centers in prehistory is just beginning to be known in the literature. Although not entirely without controversy, the records describe dramatic declines in civilized societies that have fallen at the same time as extreme drought events. Three examples of this from the archaeological records are: the Akkadian Empire in Mesopotamia (present day Iraq) from around 2200-1900 BCE, the Mayan Civilization in Yucatan from 810-910 CE, and the Chaco Canyon Anazasi (present day Southwest U.S.) from about 1110-1300 CE (deMenocal, 2001; Weiss and Bradley, 2001; Kolbert, 2005). Each suffered relatively rapid declines that were probably associated with more multifaceted events than solely climate change. For example, Diamond (2005: 11-15) has surveyed the collapse of a number of complex, advanced societies, and he identified several attributes that contributed to their decline and extinction. *First*, population increase in numbers and density exert pressure on the environment, and there is ecological damage, such as salinization from irrigation, deforestation, and soil loss. *Second*, there is loss of support by neighbors leading to isolation and a lack of buffering against a variety of problems. *Third*, there is armed conflict that may be a function of declining resources leading to political expansion. Alternately, the society may be viewed as vulnerable by its neighbors. *Fourth*, the political and societal response to problems is counterproductive and leads to a worsening of the society's ills. The political or governing structure may become weakened or corrupt. *Fifth*, natural climate change extremes (drought or a series of droughts) may push the society over the brink and lead to a collapse. This is not to say that climate change is the major cause of societal collapse, but rather it may be a crucial factor when a society is weakened from other causes.

Perhaps the best-documented example of the effects of drought on a high civilization is the case of the Mayan collapse. This occurred during the Terminal Classic Period of the Mayan Civilization from 700-950 CE. The human population in Yucatan had increased to between 3 and 13 million during the period of expansion after 550 CE, forest resources were being depleted, and agriculture depended on rainwater because of shallow groundwater levels. From sedimentary deposits from the Cariaco Basin off the coast of Venezuela, Haug and colleagues (2003, Peterson and Haug 2005) demonstrated that a series of multiyear droughts struck the Yucatan Peninsula between 810 and 910 CE. These disastrous droughts resulted from the southward shift of the Intertropical Convergence Zone (ITCZ) and its associated rainfall in the Caribbean during the 9th century CE. As Diamond (2005) and many archaeologists would argue, although population increase, environmental degradation, and political disruption led up to the collapse, drought may have been the final blow leading to the dissolution of the Maya Civilization and the dramatic human population decline that followed.

Contemporary climatic events that lead to extremes include a slight reduction in rainfall in the tropics, but not the subtropics, through the 1980s and 1990s. These trends have been paralleled by 20th century increases of 7 to 12 percent in precipitation in temperate zones between 30° N and 85° N latitude (Houghton et al., 2001: 142-143). There is also some indication that precipitation events have increased in intensity. As with temperatures, any shift in the distribution of precipitation is likely to increase the frequency of extreme events – at the right side of the distribution, heavy rainfall events; at the left side of the distribution, droughts of varying intensities (Houghton et al., 2001: 155).

SEA LEVEL RISE AND DECREASED LAND AREA

Global warming has already led to sea level increases of between 10 and 20 cm (4"-8") during the past century. This is greater than the rise during the 19th century. Predicted increases from the years1990 to 2100 range from 9 to 88 cm (3.5-35"), and have a central value of 48 cm (19") (Houghton et al., 2001: 641). The source of these increases includes thermal expansion of the oceans, melting of mountain glaciers, thawing of permafrost, and melting of continental ice sheets covering the Antarctic and Greenland. But even if greenhouse gases are stabilized or reduced during the next century, thermal expansion and melting ice will continue for several hundred years because of the inertia of the warming process. Complete melting of the Greenland and Antarctic continental glaciers would contribute to a rise in sea level of about 10 meters, but this would require very warm global temperatures for several millennia. Nevertheless, evidence is accumulating that both the Antarctic and the Greenland continental glaciers are declining, partly from meltwater erosion and undermining by seawater (Kerr 2006). Hence, a best prediction for the 21st century is a sea level rise of about 0.5 meter, which will jeopardize many coastal areas around the world.

Areas at risk with sea level rise include densely populated coastal and lowland areas that include the Nile, Amazon, and Mississippi Deltas, coastal cities, the Netherlands, and coastal areas of South and East Asia, the southern Mediterranean, the African Atlantic, and the Caribbean (O'Neill et al., 2001: 27). Particularly vulnerable are many low-lying Pacific islands and atolls that would be totally inundated with modest sea level rises. With sea level rising, the effect of storm surges will be enhanced and probably double the 46 million worldwide who are at risk of flooding from storm surges today. It is estimated that an average of 35 meters of shorefront around the world will be lost if the average sea level rise of 48 cm takes place in the 21st century. This loss of land will vary globally according to land subsidence, soil erosion, earthquakes, and storm surge activity. Land subsidence in heavily populated coastal areas may occur because of overuse of water aquifers and depletion of ground water.

A few of many examples can be given of areas at high risk to sea-level rise around the world. Along the China coast, sea level rise was about 2.3 mm/year over the past 30 years, a value higher than the global average because of earthquake and groundwater-depletion subsidence (Han et al., 1995). Deltaic subsidence in Chokaria Sundarbans, Bangladesh has resulted in an even greater sea level rise of 5.5 mm/year (Hug et al., 1995). In the Pacific, records over the past 90 years from Samoa indicate that there has been a shoreline recession of nearly 0.5 meter/year (Nunn, 1997). In Bermuda, rising sea level is inundating mangrove forests with saltwater (Ellison, 1993). Finally, the Chesapeake Bay in the United States has experienced marshland and island loss amounting to the submerging of about one third of the Blackwater National Wildlife refuge (Irmler and Wiese, 1997).

The rise in sea level from global warming has enormous destructive potential around the world. According to McCarthy et al. (2001: 345-346), coastal systems are subject to:

- Increased levels of inundation and storm flooding (e.g., Bangladesh)
- Accelerated coastal erosion (e.g., Samoa)
- Seawater intrusion into fresh groundwater (e.g., Florida, United States)
- Encroachment of tidal waters into estuaries and river systems (e.g. Blackwater National wildlife Refuge, United States)
- Elevated sea-surface and ground temperatures

These coastal changes contribute to an increased vulnerability of already overpopulated zones in many parts of the world.

INCREASED ULTRAVIOLET RADIATION

As noted, ozone depletion in the stratosphere has resulted from enhanced human production of chlorofluorocarbons (CFC) and aerosols, such as sulfates (from industry), organic carbon, nitrates, dust, and black carbon or soot (Menon, 2004). CFC and some aerosols (black carbon) contribute to global warming, whereas other aerosols (sulfates and organic carbon) can bring about cooling effects. Ozone depletion allows greater amounts of ultraviolet radiation (100-400 nm) to reach the surface of the earth, which can have an impact on the biosphere through multiple pathways. UV influences on human health are largely through sunburn damage to the skin, various forms of skin cancer, skin aging, eye damage (e.g., cataracts, photokeratitis, pterygium) and immunosuppression, largely by ultraviolet B (280-320 nm) radiation (Bentham, 1993; Diffey, 1991; Halliday et al., 2004; Noonan and De Fabo, 1992; Robins, 1991: 59-60, 189-192). These relationships are illustrated in Figure 5.

The greatest damaging effects of current UV radiation are on fair-skinned European and European-derived populations, particularly those who live in equatorial or arid zones with bright sunlight. Melanin skin pigmentation, which serves a protective function for the skin against actinic UV radiation, is distributed in human populations according to the evolutionary history of these populations. That is, populations who were exposed to bright sunlight in the past have been selected for deep melanin pigmentation in both the skin and the eyes. Conversely, those who were resident in temperate zones have experienced relaxed selection for melanin and positive selection for pale skin in order to synthesize vitamin D more effectively (Robbins, 1991). The distribution in human populations of melanin pigmentation prior to the age of European expansion reflected these evolutionary patterns more so than today, where, because of widespread migration, humans with all levels of melanin pigmentation are distributed throughout the tropics and temperate zones.

Five hundred years of human migrations leading to fair-skinned populations in the tropics and heavily pigmented populations in cloudy temperate zones have set up conditions for natural experiments of human adaptation to climatic variation (Garruto et al., 1999). In one natural experiment, South Asian migrants to the United Kingdom developed rickets and osteomalacia from a combination of heavy melanin pigmentation, ghetto residence and cloudy climate, limited vitamin D synthesis, and calcium-binding Indian cuisine (Little and Baker, 1988). In other natural experiments, British migrants to Australia have one of the highest rates of skin cancer in the world, where one out of two Australians will develop skin cancer in their lifetime (malignant melanoma,

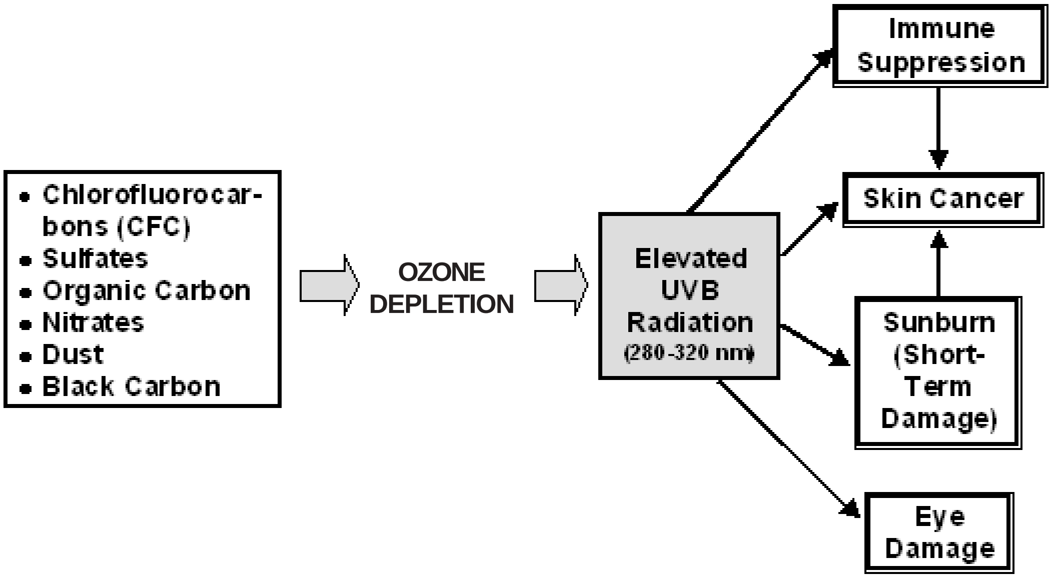

Fig. 5. A simple model of relationships among parameters leading to ozone depletion and increases in ultraviolet B radiation and the impacts on human health.

squamous cell carcinoma, or basal cell carcinoma) (South Australia Cancer Registry, 2003). Also, susceptibilities to basal and squamous cell carcinomas are greatest when fair-skinned (northern- and western-European derived) individuals migrate to areas such as Australia with bright sunlight before they reach adolescence (Diffey, 1991). Laboratory studies of neonatal mice have confirmed reported risks of cancer in early exposure to UV radiation from epidemiological data on children (Noonan et al., 2001).

Martens (1998: 127-146) conducted simulations to predict rates of basal cell carcinoma, squamous cell carcinoma, and melanoma skin cancer under different projections of stratospheric ozone depletion from the late 1970s to the year 2050. Simulations were applied to the Netherlands and Australia. Risks of mortality for each form of cancer are: 0.3 percent for basal cell carcinoma, 3.0 percent for squamous cell carcinoma, and 25 percent for melanoma skin cancer. Several projections were applied based on the Intergovernmental Panel on Climate Change (IPCC) predictions (IS92a Scenario) and the landmark 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (Rowlands, 1993), which called for and predicted controls of chlorofluorocarbons (CFC) throughout the 1990s and into the 21st century. Ozone depletion-related cases of these three forms of skin cancer were projected to the year 2050 from a baseline of zero in 1978. These projected cases of skin cancer for 2050 ranged from 6/100,000 to 50/100,000 in the Netherlands and from 35/100,000 to 375/100,000 in Australia (Martens 1998: 143). A best-case scenario (halting production of CFC immediately) would still lead to thousands of excess (UV-related) cancer deaths because of the slow stratospheric ozone recovery time. What is not considered here are the health costs of managing the many thousands of non-lethal cases of skin cancer generated by increased UV radiation.

Although skin cancer is the most dramatic form of skin damage, there are other major health threats from elevated UV levels. Sunburn in fair skinned individuals can be debilitating and cause permanent damage to cutaneous tissues and enhance aging of the skin (Robbins, 1991: 190). Severe epidermal damage from sunburn can also impair thermal sweating, and hence reduce heat tolerance and evaporative cooling. Finally, the immunosuppressive effect of UV radiation, in addition to its relationship to cancer, may have a profound impact on infection because of the immunogenic function of skin as a first defense against microorganisms (Kripke, 1994).

ECOLOGICAL DISRUPTION AND LOSSES IN BIODIVERSITY

Prior to 10,000 years ago, the impact of our species on the earth was minimal and we were truly an integral component of the biosphere. As human populations grew, congregated in nucleated settlements, developed agriculture, migrated throughout the globe, and began transforming the landscape, their destructive influence on other species and ecosystems increased. At this time, we are experiencing a dramatic loss of global biodiversity that is a direct result of human population expansion, exploitation of biotic resources, industrialization and pollution, human land use and habitat fragmentation of wild species, and a variety of other anthropogenic causes (Wilson, 1988; Reaka-Kudla et al., 1997).

The value of biodiversity on the planet should be self-evident, but can be identified according to relative importance. Of greatest value is the role that life plays in maintaining the climatic and energy balance on the planet; that is, the balances that are maintained in atmospheric CO_2, O_2, N_2, and ozone that are the result of interactions among elements of the biosphere and solar and planetary forces. Despite considerable variation in terrestrial climate over the past four million years, our species and its ancestors have been able to survive and evolve. On the other hand, a major disruption of life on the earth could trigger an abrupt or "threshold" climate change that would be disastrous for human existence (Alley et al., 2003). Second in importance, ecological processes in the biosphere require symbiotic relations among a variety of life forms that are essential for maintenance of humans and other species. Bacteria, protozoa, fungi, insects, and plants are all essential for the normal functioning of ecosystems within the biosphere — the life-support systems within the biosphere (Patrick, 1997). Third, humans depend on innumerable products from biological diversity that include: foods, fiber, drugs, and knowledge about how biological mechanisms operate (May, 2002). We are just beginning to understand these complex characters of biochemistry and physiology that have been produced by the selective processes of evolution. Finally, as May (2002) noted, we have an ethical responsibility of stewardship of the planet to our descendants, which can be identified, fundamentally, as a moral responsibility not to destroy our home planet.

May (1997, 2002) estimated numbers of eukaryotic species extant on earth today at around 7 million (1.5 – 1.8 million have been described), and further estimated that extinctions will be 10,000 times greater than background (natural extinctions) over the next century. Pimm and Brooks (1997) provided estimates of equally alarming extinction rates at 1,000 to 10,000 times greater than background beginning to appear by the year 2050. However, approximations of species extinctions do not take into account the loss of biodiversity in population numbers (reduced variation within species) and in ecosystem variation (breakdown and loss of ecosystems). Nor do these estimates take into account the effects of global warming on species extinctions or other losses of biodiversity. Global warming is a new anthropogenic threat to biodiversity. Global warming can affect biodiversity in a variety of unanticipated ways. For example, forest wildfires are believed to be increasing in the western United States because of increased spring and summer temperatures, summer drought, and an earlier spring snowmelt (Westerling et al., 2006). At the same time that forest habitats are being destroyed by fire, carbon dioxide is being released into the atmosphere further contributing to the greenhouse effect.

In a collection of papers edited by Lovejoy and Hannah (2005a) the impact of global warming on biodiversity was considered. Ongoing changes in marine, freshwater, and terrestrial eco-systems linked to climate change were document-ed, based on past and present evidence. In one contribution, three alternatives were identified for organisms experiencing climate change: *adapt, move, or die* (Hewitt and Nichols, 2005). In many cases, rapid climate change will cause some individuals to die, reducing genetic variation and the adaptability or adaptive capacity of the population. Migration or movement then becomes the only alternative means of survival.

In the last chapter Lovejoy and Hannah (2005b) focus on ways to reduce greenhouse gases, and hence to slow the process of global warming. Practically, the alternatives are limited to reducing CO_2 emissions and/or sequestering excess CO_2, but the prospects of significant advances are not good. The authors caution that: "Unless this debate is joined, an acceptable target agreed, and action rapidly taken, the sixth great extinction event on earth will be ensured by increasingly fragmented habitat combined with the biological dynamics resulting from climate change" (p. 395). It is quite clear that there are no easy solutions to losses of biodiversity in a biosphere with anthropogenic climate changes superimposed on other anthropogenic environmental changes.

DISCUSSION AND OVERVIEW

Anthropogenic global climate change has been established without any reasonable scientific doubt by extensive research and computer modeling efforts. A major compilation by the multinational Intergovernmental Panel on Climate Change (IPCC) is its Third Assessment Report published in 2001. The World Meteorological Organization and the United Nations Environment Programme (UNEP) established the IPCC in 1988. This report, in four heavy volumes, including a synthesis report, describes in considerable detail the work and modeling of climate change by hundreds of scientists (Houghton et al., 2001; McCarthy et al., 2001; Metz et al., 2001; Watson et al., 2001). A number of "mitigation" scenarios or future possibilities for greenhouse gas emissions have been presented: each depends on a variety of political, policy, social, and economic considerations. Many of these scenarios target a CO_2 level of 540 ppm as an achievable goal by the mid- to late-21st century (Metz et al., 2001: 21-25). Whether or not these mitigation projections are realized, global warming will continue because of the energy inertia of the earth.

There are a number of uncertainties concerning scenarios that depend on, for example, national and international decisions and agreements, political interests and policies, the effectiveness of social movements and actions, the effectiveness of population controls, the frequency and geographic locations of climate-related disasters, and other issues. International agreements such as the Rio Accord in 1992 and the Kyoto Protocol in 1997 have been ineffective in limiting greenhouse gas emissions because nations are concerned about economic and political outcomes within the international arena. Many governing bodies are less effective at long-range planning than on short term, particularly in the context of political self-interests.

The outcomes of global warming on human health will be wide-reaching and will present humanity with new public health problems. Heat waves will increase with elevated heat-related deaths and illnesses. The greatest impact of heat waves will be on temperate zone urban populations, the poor, the elderly, and those already ill. High latitude populations will be required to change subsistence patterns and lifestyle as melting ice, snow, and permafrost change the ecology of these areas. Food security will decline in many parts of the developing world that are subject to periodic drought. Increased drought in seasonally semi-arid areas will lead to more crop failures and livestock losses. Food security will be compromised in other areas with heavier than normal rainfall, because of flooding and increased infestation of cultivated plants. In addition to food security threats, flooding will also increase the prevalence of diarrheal diseases due to contamination of drinking water sources. As warmer nighttime temperatures and generally milder weather moves toward higher latitudes and higher altitudes, vector-borne diseases such as malaria and dengue fever will appear in these areas. Other vector-borne tropical diseases will appear in areas previously free of the infections. Because of rising sea level, riverine, estuary, and coastal communities will lose land area, be more vulnerable to storm surges and floods, be more susceptible to water-borne diseases through contamination of fresh water supplies, and lose the capacity to deal with sewage. Ozone depletion in the stratosphere will lead to increased prevalence of skin damage and skin cancers in fair-skinned individuals. Loss of biodiversity from continuing human population growth and global warming will stress some ecosystems to the breaking point, further affecting human food security.

Vulnerability is often cited in the IPCC reports as an important variable in the mix of climate change. What is most clear is that vulnerability to the effects of climate change is most acute in the developing world where public health support – minimal at best – will be overwhelmed by the warming effects, loss of limited food security, and likely increases in infectious diseases. The less vulnerable industrialized nations will need to direct more of their resources to controlling the effects of climate change, causing geopolitical stresses that can lead to armed conflict and warfare. Climate change is a challenge to human adaptability that is probably equal in importance to the threats of nuclear conflict and human population outstripping its food and energy resources.

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ABSTRACT Climate change is a normal consequence of terrestrial and solar processes that act on the earth. Over the past century, however, human activity has produced a form of climate change that is qualitatively different from past patterns. This anthropogenic climate change has resulted from exponential human population growth and support of this ever-expanding population. Industrialization, consumption of fossil fuels, extensive agriculture, deforestation, and pollution all contribute to or are by-products of this support. The two primary components of anthropogenic climate change are (1) global warming and (2) increased ultraviolet radiation. In the first case, global warming has resulted from increased human production of greenhouse gases, such as CO_2, which have led to a net heat gain at the surface of the earth. In other words the earth is heating up, and there are both predictable and unpredictable consequences of this thermal imbalance. In the second case, the escape of chlorofluorocarbons (CFCs) and other volatile organic chemicals have led to the partial destruction of ozone in the stratosphere, which acts as an effective filter to screen ultraviolet (UV) radiation. Global warming has far-reaching implications for human health and well being, and can affect food production, land availability, fresh water resources, disease transmission, earth's biodiversity, and a host of other factors. Increased UV radiation also threatens human health through skin damage, cancer, and immune function impairment. In this review, climate change is discussed in the context of human health and adaptability at both the individual and the population levels. There are likely to be major threats to human health from climate change, and many of these are beyond our immediate or long-range control.

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