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# Chapter 7
# CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT

**John Lemons[1]**
**Rudolf Heredia[2]**
**Dale Jamieson[3]**
**Clive Spash[4]**

## 1. Introduction

One of the environmental problems Agenda 21 focused on is protection of the atmosphere. Programs to protect the atmosphere include: (1)improving the scientific basis for decisionmaking, including addressing scientific uncertainties; (2)promoting sustainable development by better use of energy and consumption of materials, transportation, industrial development, and terrestrial and marine resources; (3)preventing stratospheric ozone depletion; and (4)mitigating transboundary air pollution.

The objective of the program to improve the scientific basis for decisionmaking is to facilitate understanding of physical, chemical, and biological processes that influence and are influenced by the earth's atmosphere on global, regional, and local scales and to improve understanding required for mitigation of threats to the atmosphere. The basis for action is the increased concern about the effects of climate change and atmospheric pollution that has created new demands for scientific knowledge to reduce uncertainties.

The objective of the program to promote sustainable development is to reduce adverse effects on the atmosphere from the energy sector through less polluting and more efficient energy production and use, particularly by the development of renewable energy sources. Importantly, this program recognizes the need for equity, adequate energy supplies, and increasing energy consumption in developing countries. It also suggests a consideration for the situations of countries that are dependent on the income generated from the production and consumption of fossil fuels and associated energy-intensive products for which countries have difficulties in switching to alternatives, and of countries that are highly vulnerable to the adverse effects of climate change.

The program objectives to prevent stratospheric ozone depletion are based on concern about the increasing concentrations of reactive chlorine, bromine, chloroflurocarbons (CFCs), halons, and other substances. While this program recognizes that the 1985 Vienna Convention for the Protection of the Ozone Layer and the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer (amended in London in 1990) were important steps to protect the ozone layer, the total chlorine loading of the atmosphere of ozone-depleting substances has continued to rise. Consequently, further measures to reduce this loading in

[1]Department of Life Sciences, University of New England, Biddeford, ME 04005, U.S.A.; [2]Social Science Centre, St. Xavier's College, 5, Mahapalika Marg, Bombay 400 001, India; [3]Department of Philosophy, University of Colorado, Boulder, CO 80309, U.S.A.; [4]Department of Economics, University of Stirling, Stirling FK9 4LA, Scotland.



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the atmosphere through compliance with control measures identified in the Montreal Protocol are needed.

The objectives to mitigate the effects of transboundary air pollution on human health and ecosystems focus on ways to improve the lack of reliable emissions data outside of Europe and North America and on the need to acquire better information on the environmental and human health effects of air pollution.

Clearly, the language contained in the aforementioned programs' objectives mandates the use of science, economics, and ethics. In addition, Agenda 21 includes other recommendations calling for the use of these disciplines in protection of the atmosphere. For example, it calls on the sciences for better understanding and prediction of the various properties of the atmosphere and of affected ecosystems, as well as health impacts and their interactions with social and economic factors. Further, scientific knowledge is required to identify threshold levels of atmospheric pollutants and greenhouse gases that would cause dangerous levels of anthropogenic interference with the climate system and the environment and to identify the associated rates of changes that would not allow ecosystems to adapt naturally.

Many recommendations to protect the atmosphere refer to the necessity to base decisions on economic methods of analysis and information. Recommendations refer to energy as being essential to economic and social development and improved quality of life, and they refer to the need to develop at the national level appropriate methodologies for making integrated energy, environment, and economic policy decisions for sustainable development through environmental impact assessments. Many recommendations discuss the need to achieve environmental protection by the use of cost-effective policies.

Ethical considerations also are apparent in recommendations to protect the atmosphere. For example, energy sources need to be used in ways that respect the atmosphere, human health, and the environment as a whole. Recommendations call for taking into full account the legitimate priority needs of developing countries for the achievement of sustained economic growth and the eradication of poverty. Many recommendations stress the need to develop equitable solutions to problems of protecting the atmosphere and achieving sustainable development.

Although application of science, economics, and ethics is required for implementation of Agenda 21 recommendations to protect the atmosphere, many problems regarding their application need to be resolved. For example, the status of scientific knowledge about the state of the atmosphere needs to be understood, particularly with reference to the determination of how certain we are of such knowledge and what its predictive capabilities are. In addition, because scientific uncertainty about the state of the atmosphere is prevalent, conclusions about the atmosphere often are more value-laden than is commonly thought. Economic tools and methods are required to assess problems of the atmosphere and how to resolve them by the application of cost-benefit analysis and/or alternative methods of valuation; application of such methods often is controversial. Although sustainable development and environmental protection fundamentally is an ethical problem, the language of Agenda 21 is not prescriptive with respect to the ethical criteria that should be used to resolve intergenerational or intragenerational conflicts among humans, how to resolve conflicts between humans and the nonhuman environment, or who should decide and on what basis how conservative or precautionary decisions should be given scientific uncertainty.

In this chapter we: (1)summarize the scientific basis for climate change and its projected environmental consequences, including areas of scientific uncertainty; (2)analyze the ethical implications posed by problems of climate change; (3)analyze the adequacy of traditional and alternative methods of economic analyses used to assess climate change problems; and (4)present a representative perspective of southern nations' views on problems of protecting the atmosphere.

Protection of the earth's atmosphere requires consideration of problems due to increasing concentrations of greenhouse gases, acid precipitation and other air pollutants, and global ozone depletion. While these problems have many common features, all are complex and controversial (IGBP 1990). An adequate treatment of all of these problems is not possible in a single chapter. Consequently, we focus mostly (but not exclusively) on global climate change due to increased concentrations of greenhouse gases, primarily carbon dioxide. We do this for several reasons. First, global climate change is likely to have the most significant impacts on humans and the environment. Second, the effects of other principal air pollutants are known with more scientific certainty and are regulated to a greater extent by laws of many nations. Third, conventions and voluntary measures have been established to begin the regulation of ozone-depleting chemicals. Fourth, the United Nations Environmental Programme recommends that climate change studies focus on carbon dioxide (Hogan et al. 1991).

## 2. Scientific Assessment of Climate Change

### 2.1. WARMING OF THE EARTH-ATMOSPHERE SYSTEM

Equilibrium of the temperature of the earth-atmosphere system is maintained by a balance between the amount of incoming solar energy absorbed by the system and the amount of outgoing radiant energy. Most of the outgoing radiant energy is in the long-wave or infrared region, in the wavelengths of 4 to 100μm. Numerous human activities have the potential to cause significant climate change by altering the factors responsible for maintaining the temperature equilibrium of the earth-atmosphere system. Such activities include: (1)release of carbon dioxide by burning of fossil fuels; (2)release of methane, chlorofluoromethanes, nitrous oxide, carbon tetrachloride, and carbon disulfide; (3)release of particles and aerosols from industrial and agricultural practices; (4)release of heat; (5)upward transport of chlorofluoromethanes and nitrous oxide into the stratosphere; (6)release of trace gases such as nitrogen oxides, carbon monoxide, or methane that increase tropospheric ozone by photochemical reactions; and (7)patterns of land use and deforestation. The primary reason that the listed chemicals (so-called greenhouse gases) potentially can cause warming of the atmosphere is because they absorb radiant energy in the infrared region and because they have long residence times in the atmosphere.

Greenhouse gases have increased since preindustrial times (c. 1750-1800). Carbon dioxide has increased from about 280 ppmv to 354 ppmv, methane from 0.8 ppmv to 1.74 ppmv, CFC-11 from 0 pptv to 280 pptv, CFC-12 from 0 pptv to 485 pptv, and nitrous oxide from 288 ppbv to 312 ppbv. Annual rates of increase are approximately 0.5 percent for carbon dioxide, 0.9 percent for methane, 4 percent for CFC-11, 4 percent for CFC-12, and 0.25 percent for nitrous oxide. Residence times are estimated to be 50-200 years for carbon dioxide, 10 years for methane, 65 years for CFC-11, 130 years for CFC-12, and 150 years for nitrous oxide. Between 1980 and 1990, carbon dioxide is estimated to have accounted for about 55 percent of the change in radiative forcing, methane 15 percent, CFC-11 and CFC-12 (combined) 17 percent, and nitrous oxide 6 percent (IPCC 1990). However, Hansen et al. (1988) suggest that the total greenhouse effect is now due slightly more to other gases collectively than to carbon dioxide alone.

Data for the quantities of carbon found in the climate system provide an example of how humans have modified the amount of chemicals found there. Presently, the atmosphere contains about 750 Gt of carbon, compared with about 575 in the preindustrial atmosphere. The annual release of carbon to the earth's atmosphere is more than 5 Gt from the burning of fossil fuels and is about 2 Gt from deforestation. The amount of carbon stored in all of the earth's phytomass is approximately 560 Gt, compared with 4,000 Gt stored in recoverable coal and oil and 5,000-10,000 stored in potentially recoverable fossil fuels. Because a large amount of carbon is stored in recoverable and potentially recoverable fossil fuels relative to the amount in the atmosphere or phytomass, there is considerable potential for the amount of atmospheric carbon to increase if humans burn fossil fuels in large amounts or at rapid rates. Most of the carbon added to the earth-atmosphere system since 1860 has come from the burning of fossil fuels (Clark 1982).

Based on apparent correlations between atmospheric carbon dioxide concentration and temperature change over the past 160,000 years and the past 100 years, respectively, there is presumptive evidence that an increase of atmospheric carbon dioxide concentration has resulted in an increase of the earth's atmospheric temperature (Hansen and Lebedeff 1987). However, other factors such as variations in the energy output of the sun, levels of sulphur-oxides, land use changes, and volcanic eruptions also can contribute to temperature increases. Consequently, the relationship between past increases in atmospheric carbon dioxide and temperature is not conclusive.

## 2.2. METHODS TO MODEL CLIMATE

Ideally, decisions on whether and how to attempt to prevent or mitigate climate change must be predicated on reasonably accurate scientific information regarding the causes of change, the magnitude and rate of atmospheric temperature increase, and the ecological and human health impacts of change (Lemons 1991).

In recent years, scientists have developed various general circulation models (GCMs) to predict future climate (Trenberth 1992). All GCMs are limited in the physical, chemical, and biological detail they can handle, as well as in the spatial detail they can resolve. Most GCMs focus on the physical climate system and ignore or use oversimplified information and assumptions about chemical processes, land surface processes, and biological or ecological processes. In addition, the feedbacks that exist in climate change, such as processes involving deep ocean circulation, oceanic biogeochemical cycling, water vapor, clouds, snow, sea ice, vegetation distribution, ultraviolet radiation and phytoplankton, and soil carbon storage, are understood poorly and infrequently included in GCMs (IPCC 1990). Because GCMs are built with different assumptions and include different factors and levels of detail and certainty, large uncertainties exist in our ability to project future climate change.

Generally speaking, a GCM is a mathematical model composed of systems of partial differential equations based on laws of physics. The equations describe basic atmospheric processes such as large-scale wind, temperature, and distribution in the atmosphere and surface climate. The GCMs also incorporate with varying degrees of success interactions with oceans, clouds, land surfaces, and sea ice. Equations used in GCMs are too complex to be solved analytically; they must be converted to arithmetic form suitable for computations by digital computers. The GCMs are run with the current carbon dioxide concentration until it reaches a steady state; this represents an experimental control. Typically, subsequent runs are made using two or three times the current concentration of atmospheric carbon dioxide. After these types of runs are completed, they are compared to determine the changes caused by increased atmospheric carbon dioxide.

Most GCMs represent the earth-atmosphere system in a three-dimensional grid system. Depending on the model, horizontal spacing of grid points ranges between 4° to 8° latitude and 5° to 10° longitude, with 2 to 12 vertical atmospheric layers extending to 30 km above the surface (Schneider 1991). A few models have higher resolution grids of approximately 2.5° by 2.5°. No models are likely to be developed within the foreseeable future with grids less than 100 km by 100 km, which is far larger than the scale of most ecological research and microclimate processes (Root and Schneider 1993).

Once models are developed, attempts need to be made to verify their predictive capabilities. Generally, three methods of verification exist; none by itself is sufficient (Schneider 1992). The first method checks model simulation against present-day seasonal cycles of surface air temperature. Such a method provides verification of rapid processes, such as cloud formations. But it does not provide verification of slow changes that occur over long time periods for variables such as ice cover, soil organic matter, or deep-ocean temperatures. A second method of verification tests individual components of a model directly against real data. For example, upward infrared radiation emitted from the earth can be measured from satellites and compared with predictions made by GCMs. This method of verification does not, however, guarantee that the net effect of the interacting components of a model has been defined or accounted for properly. A third method of verification is an a priori one, in that some researchers have more confidence in models that include a maximum amount of spatial resolution and physical, chemical, and biological data. The problems of verifying GCMs introduces additional uncertainty into our confidence in the predictive capabilities of GCMs.

Various attempts have been made to verify predictions made by GCMs. For example, the IPCC (1990) compared observed mean global temperature changes from 1861 through 1989 with values predicted by GCMs. The typical prediction of 0.5 to 1°C warming over this century is consistent generally with, but larger than, that observed. Schneider (1992) provides the following possible explanations for the discrepancy: (1)the sensitivity of the models to greenhouse gases has been overestimated by a factor of two or so; (2)modelers have not accounted properly for external factors such as volcanic dust, changes in solar output, or regional tropospheric aerosols from biological, agricultural, and industrial activities; (3)modelers have not accounted for the large capacity of the oceans to absorb increased heat from the atmosphere; (4)both present models and observed climatic trends could be correct, but models typically are run for equivalent doubling of carbon dioxide, whereas the world has experienced only a quarter of this increase; (5)the incomplete and inhomogeneous network of thermometers has underestimated warming; and (6)there may have been a natural cooling trend of up to 0.5°C during this century. Although global temperature trends and those anticipated by GCMs disagree somewhat, the difference may not be fundamental. Depending on what assumptions one makes about the above explanations for the discrepancy, the observed temperature trend could be consistent with an equivalent doubling of carbon dioxide and an equilibrium temperature response of 0.5 to 5.0°C.

To be valid, climate models also must be able to differentiate atmospheric temperature increases and changes of other climate variables from the natural variation of climate that occurs over both short and long time periods. Characteristically, this includes periods of several days, periods ranging from about 10 days to a season, periods of several years, and periods of decades or longer. Only limited observational and modeling efforts have been devoted to climate variability on time scales of decades and longer. The natural variability of climate makes the detection of changes due to human activity difficult, especially given the fact that greenhouse gas-induced mean atmospheric temperature increases are expected to occur at a rate of between 0.1 and 0.8°C per decade (IPCC 1990). This rate of increase is within the magnitude of natural mean atmospheric temperature fluctuations.

Climate models also have been used to estimate the immediate reduction in emissions for stabilization of greenhouse gases at present atmospheric levels (Lashof and Tirpak 1989, IPCC 1990). In order to stabilize greenhouse gases at present atmospheric levels, estimates indicate that carbon dioxide, nitrous oxide, and CFCs would need to be reduced by approximately 60 percent or more; methane would require a reduction of about 15 percent. It is important to note that results from climate modeling indicate that the longer emissions continue at present rates, the greater will be the reductions in future emissions that will have to be made to stabilize atmospheric carbon dioxide concentrations at a given level.

## 2.3. PROJECTED CLIMATE SCENARIOS

Because of limited knowledge, various projections of future mean annual atmospheric temperature increases have been made. A number of modeling studies have yielded projections of future mean atmospheric temperature increases in the range of 2.8 to 5.2°C by the end of the next century for a doubling of atmospheric carbon dioxide concentration (see, e.g., Washington and Meehl 1984, Wetherald and Manabe 1986, Wilson and Mitchell 1987, Schlesinger and Zhao 1989, IPCC 1992, Trenberth 1992). However, some estimates of temperature increases based on models that attempt to take into account full ocean processes are in the range of 1-2°C (Washington 1992). The IPCC provided a best estimate of 1 to 2°C warming by the year 2030 and 3°C warming by the end of the next century (Tolba 1991). Projected rates of temperature increase are 0.2 to 0.8°C per decade. This rate of warming is greater than that ever experienced in human history. The differences between various models are difficult to understand because their construction varies and the feedback mechanisms may be substantial. Models also have projected the geographical distribution of temperature increases from a doubling of atmospheric carbon dioxide concentration (Washington 1992); warming of about 2-3°C in the tropics and up to 20°C in the winter poleward regions is projected. However, geographical regions at the same latitude are projected to experience different amounts of warming.

Two recent studies indicate that long-term climate warming may be more serious than has been projected by earlier studies. Manabe and Stouffer (1993) ran their climate model to 500 years into the future. The eventual quadrupling of carbon dioxide during the next 140 years implied by current trends would increase temperature by 7°C or more. During the first 50 years of this period, there would be a drastic reduction in the ocean currents that flush the deep sea with oxygen-rich waters, lift nutrient-rich deep waters to the surface, and carry heat toward the polar regions. Projected consequences include a decrease in the oxygen levels of the ocean and a nearly stagnant deep circulation, eventually killing off much ocean life. Walker and Kasting (1992) took into account the rate at which the ocean and vegetation remove carbon dioxide from the atmosphere and assumed that conservation of fossil fuels would slow the emission of atmospheric carbon dioxide but would not stop it eventually. They then ran their climate model for different conservation scenarios. If the rates of fossil fuel use and deforestation continue as they have over the past few decades, it was found that the atmospheric concentration of carbon dioxide would be more than seven times preindustrial levels by the 23rd century. If fossil fuel use remains at today's level, the concentration of atmospheric carbon dioxide reaches seven times the preindustrial in the year 2700. Ending deforestation would lower the peak carbon dioxide concentration to four times preindustrial levels. Projected mean atmospheric temperature increases are on the order of 10°C. According to this model, the only way to limit the rise in carbon dioxide to a doubling of preindustrial levels is to reduce present emissions by a factor of approximately 25—something neither the developing nations nor the developed nations are likely to accomplish.

## 2.4. PROBLEMS OF DETECTION

Detection of climate warming due to increased emission of greenhouse gases requires careful evaluation of signal-to-noise ratios to be sure apparent change is not due to random fluctuations. The approximate 0.5°C or so mean atmospheric temperature increase observed during the past few decades has been attributed to natural fluctuations by some researchers (Klein 1982) and to statistically significant warming by others (Hansen and Lebedeff 1987). Consequently, it is not possible to conclude with confidence that atmospheric warming has occurred.

Detection of climate warming due to increased concentrations of greenhouse gases will require evidence that warming is due to such emissions and not due to some other factor(s). Researchers have proposed measuring various physical factors in order to discern whether any observed atmospheric warming is attributable to greenhouse gas emissions. These factors include surface temperature, temperature in the stratosphere, temperature in the troposphere, infrared radiation, the cryosphere, the oceans, and hydrologic variables. Measurements of these factors are problematic in that they have statistical or random fluctuations. Further, researchers disagree on the priority of their importance in detection of greenhouse gas-induced warming.

## 2.5. ENVIRONMENTAL IMPACTS

Climate change may result in many impacts to ecosystems, species, and humans. Ideally, scientific studies should be able to provide knowledge required for making informed decisions regarding mitigation or prevention of adverse impacts of climate change. Following, we provide a brief descriptive summary of the status of knowledge regarding some of the impacts of climate change on ecosystems, species, and humans. We provide a more detailed analysis of the status of knowledge for global ecological impacts in order to show some of the approaches used to acquire knowledge about climate change impacts.

### 2.5.1. *Assessing Greenhouse Gas Emissions and a Greenhouse Gas Index*

The patterns of greenhouse gas emissions vary between different countries (WRI 1992). Cumulative emissions of carbon dioxide for 1950-1989 range from approximately 155 billion metric tons for the United States to 90 billion metric tons for the European Community to less than 10 billion tons for most developing nations. In 1989, per capita emissions for carbon dioxide were approximately 20 metric tons for the United States, 10 metric tons for the United Kingdom, and a little over 1 metric ton for India. As would be expected, the cumulative as well as the per capita emissions for carbon dioxide and other greenhouse gases for developed countries greatly exceed those of developing nations.

The IPCC (1990) has adopted a conceptual unit called the "global warming potential" (GWP) for comparing the impact of gases that have different lifetimes in the atmosphere and different capacities for absorbing heat. Based on its use of the GWP, countries have been ranked on the basis of their total annual greenhouse gas index and on their relative per capita greenhouse gas index. According to GWP rankings for 1989, the United States contributed approximately 18 percent of global greenhouse gas emissions, the former U.S.S.R. 14 percent, the European Community 11 percent, China 9 percent, Japan 5 percent, and India 4.5 percent. These six countries were responsible for about 50 percent of the total atmospheric impact of current emissions. Most other nations contributed less than 1 percent. On a per capita basis, the average person from the United States and other developed countries contributed significantly more to atmospheric impact than the average person from a developing nation. For example, the per capita impact of a person in the United States was about 8.7 times that of a person from China and about 14.3 times that of a person from India.

The GWP for each greenhouse gas is determined by integrating an expression for the removal rate of the gas from the atmosphere and multiplying it by an expression for the infrared absorption potency of the gas. Consequently, the GWP for a particular gas depends on the period of years over which the integration is performed, which by necessity must be somewhat arbitrary. Integration periods of 20, 100, and 500 years have been used. The GWP values are normalized so that the value for carbon dioxide is 1; corresponding values for methane and CFCs are 21 and 5,873, respectively. To calculate a greenhouse gas index, national emissions from each country are weighted by the appropriate GWP, and the result is summed to provide an estimate of the impact of a country's total emissions in carbon dioxide equivalents. Despite its use, there is not universal acceptance of the GWP approach for several reasons. First, the warming potency of a greenhouse gas depends on its concentration in the atmosphere, which in turn is dependent on assumptions about future emissions. Second, atmospheric residence times for most greenhouse gases are not known with precision; this is especially true for carbon dioxide. Residence times are determined primarily by estimates of greenhouse gas removal rates based on models of atmospheric, oceanic, and ecosystem processes that are controversial. Some scientists believe that a more reliable method to calculate a greenhouse gas index would be to use observational data rather than models of how the atmosphere behaves to determine atmospheric residence times. Third, considerable debate exists about the use of arbitrary integration periods.

Beyond these problems, no scientific consensus has emerged regarding how to develop a greenhouse gas index that is appropriate for use in public policy decisionmaking. Smith (1991) argues that economic development in most developed countries has been fostered by energy use that has resulted in a so-called "natural debt." Because of their earlier and more extensive use of fossil fuels, industrial countries have significantly larger cumulative emissions of greenhouse gases than developing nations. A natural debt occurs when greenhouse gases are emitted into the atmosphere faster than they can be removed. Consequently, the natural debt is the cumulative portion of anthropogenic greenhouse gases on a per capita basis, allowing for the different warming potencies and atmospheric residence times for each gas. Although there are many uncertainties in this approach, as an approximation, the estimated total carbon released into the atmosphere and still present as carbon dioxide is about 260 metric tons per living person in the United States, compared with about 6 metric tons for the average citizen of India.

Fujii (1990) attempts to calculate a greenhouse gas index based on concerns for intergenerational and intragenerational equity. Somewhat arbitrarily, he assumes that all persons born between 1800 and 2100 have equal rights to equal quotas of carbon dioxide emissions. His method establishes regional quotas designed to equalize per capita carbon dioxide emissions in each region for this 300-year period, with the assumption that carbon dioxide levels and world population double from present levels. On a regional basis, future generations can inherit unspent quotas. According to Fujii's method, the North American carbon dioxide quota is about one tenth of the region's present emission levels due to its longer history of intensive energy use. Agarwal and Narain (1991) developed an index that allocates the natural sinks for carbon dioxide proportional to a nation's population, and they calculate each country's excess emissions beyond what its share of the global sink can absorb. They also propose that nations that exceed their emission quotas could buy emission rights from other nations. Other alternative methods to calculate greenhouse gas indices have been developed to overcome the problem of selecting an arbitrary integration period in calculating global warming potentials by choosing a period based on discount rates employed by economists to make estimates about the future (Lashof and Ahuja 1990).

### 2.5.2. *Global Ecology*

The distribution of the world's biomes depends primarily on climate, particularly temperature and precipitation. If warming of the climate lasts for decades, biomes may adjust to the new climatic conditions by modifying structural and functional attributes and changing their boundaries, thereby approaching a new equilibrium. If significant climatic change lasts for a century or more, succession to new biomes may occur.

There are several general approaches for assessing global ecological changes; none singly or in combination are sufficient to forecast such changes. Site-specific studies focus on understanding responses of different species to climate change. These studies are based on the recognition that each species has its own unique ecological and physiological needs, and as a result, each will exhibit different responses to the rate, magnitude, and duration of environmental perturbations (Cohn 1989). Most site-specific studies are based on inductive reasoning, and while they might make use of models and make generalizations about the ecological behavior of species, their results should be interpreted as having heuristic as opposed to predictive value. In other words, the results of site-specific studies are best viewed as being relevant to the particular study areas and their conditions. Although ecologists often make generalizations based on the results of site-specific studies, these studies often contain internal inconsistencies and assumptions and are accurate, at best, in only a probabilistic sense (Cairns and Niederlehner 1993).

Based on site-specific studies, Clark (1991) has summarized ecosystem sensitivities to climate change. For example, broad-scale processes such as net primary productivity may be sensitive to small changes in temperatures and water balance in deserts, grasslands, and temperate and conifer forests. Net primary productivity seems more sensitive to changes in temperature than to precipitation changes resulting from climate change, because the magnitude of temperature changes is relatively larger. Decomposition rates and the accumulation of detritus may be more sensitive in temperate hardwood forests, because rates of decomposition slow with increased latitude to a greater degree than do production rates. Decomposition rates in hardwood forests may be more sensitive to small climate shifts compared with those in conifer forests because of the higher litter quality in hardwood forests. However, protracted climate change or large-magnitude changes potentially could have greater effects in boreal conifer forests because of their greater accumulation of organic matter. Nutrient cycles respond differently to macroclimate, microclimate, seasonality, local vegetation cover, and disturbance. Consequently, it is difficult to predict their response to climate change. Fire frequency and magnitude also are sensitive to climate change, and it is likely that drier conifer forests will display greater sensitivity to climate change than will mesic forests. Finally, existing patterns of species composition would be expected to be altered as a function of climate change and the consequent fragmentation of ecosystems that is expected to occur.

Long-term climatic changes would be significant for the tropics and the Arctic tundra. In semiarid regions, trees are susceptible to decreases in precipitation. In wet forests, trees are vulnerable to insect pests, and infestations are influenced by temperature and precipitation. In the Arctic tundra, a warming trend would cause a reduction in the permafrost; consequently, trees would grow poleward farther, the upper layers of the tundra peat would dry out, and oxidation and decay of organic matter would increase. The additional carbon dioxide and methane that would be released would enhance warming, thereby creating a positive feedback.

Other approaches to predict the responses of species or ecosystems to global shifts such as climate change have been developed. Statistical models have been used to test hypotheses or to generate descriptions of the responses of species or ecosystems to perturbations. Based on an examination of studies focusing on species invasions and deletions in ecosystems, Ehrlich (1989) and Lodge (1993) conclude that ecologists can make some powerful and wide-ranging statements about invasions. For example, they can state that the addition or deletion of one species in an ecosystem can have profound impacts on community structure and function. However, they cannot accurately predict the results of a single (particular) invasion or deletion of a species in an ecosystem.

Mechanistic models also have been used by ecologists to predict the ecological consequences of environmental perturbations. These models normally are built on the assumption that the underlying causes of ecosystem structure and function are known, along with detailed knowledge of a species' individual physiological requirements or of a population's demographic characteristics. However, Pace (1993) points out that almost all mechanistic models fail to serve as a basis for reasonable predictions because they cannot capture all of the complexities involved in determining even a single species' response to perturbations, especially if ecosystem structure or function is to be regarded as fluid and not fixed.

As a partial remedy to problems posed by use of mechanistic models, Peters et al. (1991) propose the use of comparative studies which consider the responses of many populations, communities, or ecosystems to environmental perturbations across a specified gradient, region, or larger geographic area . Comparative studies attempt to describe and answer questions about general ecosystem patterns or responses by acquiring data and making statistical inferences. The advantages of such studies are that: (1)by sampling numerous populations or ecosystems, one can develop baseline data against which to evaluate future change; (2)studies involving many species or ecosystems are more likely to document large-scale human impacts than studies focused on a few systems; and (3)they provide a means for developing probabilistic models that can forecast large-scale changes. The disadvantages of comparative studies are that: (1)statistical inferences based on regression and correlation do not lead directly to mechanistic understanding; (2)the studies may fail when changing environmental conditions extend beyond the range of a model's prediction; (3)the studies often do not detect subtle ecological interactions.

Ecosystem simulation modeling is another tool that is used to examine potential ecological responses to global climate change. Studies using GCM scenarios generally use the output of equilibrium climate experiments as their starting point to forecast ecological responses to climate change. Most models focus on either structural or functional attributes of ecosystems. Structural models focus on processes that control vegetation structure and distribution, whereas functional models focus on biogeochemical processes and cycling, nutrient dynamics, soil carbon storage, and plant production. Several aspects of ecosystem modeling determine its suitability in forecasting the consequences of climate change (Root and Schneider 1993).

There is a mismatch of scales between GCM models and ecological studies, wherein the scale of the former normally is orders of magnitude larger than the latter. Consequently, knowledge from GCMs is not able to be applied to local or even regional scales. To overcome this problem, attempts have been made to develop regional forecasts from GCMs, but these are more uncertain than those at larger scales (IPCC 1992). Another problem with linking GCM output with multiscale ecological processes is that estimates of climatic variability during the transition to a new climatic equilibrium at the local or regional scale are important determinants of a species or ecosystem response to climate change. However, such variability estimates are not able to be included in GCMs because they are not capable of including such regional information.

Linking GCMs with multiscale ecological studies is problematic because there is an unpredictability of time-evolving transient climates in regional areas (Root and Schneider 1993). Although there is a fairly uniform increase and distribution of greenhouse gases in the atmosphere, a uniform or global ecological response is not likely. The timing of responses will vary among regions, and some will be more transitory than others. Further, the character of transitory responses will be different from that of a long-term climatic equilibrium. This means that not only will ecological consequences of climate change be difficult to predict at the local or regional level but also that transitory responses are likely to increase extinction rates in local environments because the vast majority of habitats cannot be protected from transient effects through prevention or mitigation efforts (Watt 1992). Presently, climate change scenarios as used in GCMs and ecological response models apply to equilibrium conditions, whereas actual climatic and ecological changes will be transient in character until such time as equilibrium conditions are achieved.

Most climate scenario studies do not provide for linkages among plants, animals, and climate on a large scale. Assessing the effects of climate change on animals by linking GCM output with multiscale ecological studies also is complicated by the fact that while the ranges of many animals have been found to be linked to vegetation, others are more directly linked to temperature or to competition with other species (Root 1988).

Paleoecological studies also are used to assess ecological responses to climate change. Past climate changes have caused large-scale shifts in species' ranges, the species composition of biological communities, and species extinctions. A 3°C atmospheric temperature increase would result in a climate warmer than experienced in the past 100,000 years. A 4°C increase would make the earth warmer than anytime since the Eocene, 40 million years ago (Webb 1992). In addition, the projected rate of human-induced climate warming is up to 100 times faster than past natural fluctuations. Based on paleoecological data, both the rate and magnitude of projected climate warming and associated changes exceed the ability of many species to adapt. Problems posed by climate change might be more acute in poleward temperate regions, since temperature changes there are projected to be larger than the mean global increase.

Recent data have suggested that even slow temperature changes have been linked to rapid periods of species' extinction and evolution (Kerr 1993). However, the causal explanation for how climate change affects rapid extinction and evolution of species is not clear. Any increase in species extinctions would be superimposed on current extinction rates. It is estimated that from 4,000 to 6,000 species become extinct annually due to the activities of humans; this rate is approximately 10,000 times so-called natural rates. However, there are many uncertainties in the number of species that exist presently, and the actual number of species becoming extinct may be two orders of magnitude higher than thought previously (Ehrlich and Wilson 1991). While paleoecological studies may provide useful information in understanding the effects of climate change, they should be used with caution in predicting ecological responses to future climate change if the rates and magnitudes of the latter exceed the paleoclimatic data base.

Regardless of the approach used to assess ecological effects of climate change, all projected ecosystem changes may have to be evaluated in the context of increasing human interventions in natural ecosystems. Few of the world's ecosystems are free from human influence, and in many parts of the world, human intervention probably will have an equal or greater ecological impact than that of climate change in the next 50 to 100 years. Significant attempts to link ecological effects of climate change with other effects of human activities have not occurred.

### 2.5.3. *Human Health and Disease*

There have been few studies of the effects of global change on human mortality (Longstreth 1990). The effects of climate on specific diseases are difficult to assess, owing to the many different geographical conditions and controls, together with the uncertainties regarding projected magnitudes and rates of climatic change. An increase in the incidence of certain diseases and change in their geographical ranges has been postulated by some investigators as possible consequences of global warming. Examples include schistosomiasis (Weihe 1979), bacillary dysentery (WHO 1977), hookworm (CCTA/WHO 1963), malaria, dengue fever, and yaws and cholera (Brown 1977). Because the complex natural histories of diseases are influenced also by such conditions as water quality, dietary conditions, food sanitation, refuse disposal, and level of economic development and education, they must not be linked solely to climate factors.

Some of the effects of climate change on human health are observable directly. For example, statistical relationships are known to exist between temperature and mortality from heart disease, stroke, acute bronchitis, asthma, and pneumonia (Rogot and Padgett 1976). Generally speaking, there may be increases in summertime deaths for areas that experience warming trends. Although these areas might experience a reduction in winter deaths for the same diseases, the increase in summer deaths is expected to exceed the reduction in winter deaths. Sudden changes in temperature also are correlated with increases in deaths. Consequently, if climatic variability increases, morbidity and mortality also are expected to increase.

It is important to remember that adverse consequences to health from climate warming might occur in tandem with increasing exposure to UV-B radiation due to depletion of stratospheric ozone. Recent data suggest that for every 1 percent decrease of ozone there is up to a 2 percent increase in cutaneous melanoma incidence and between 0.3 and 2 percent increase in mortality due to the melanoma (EPA 1987). The role of UV-B also has been confirmed in inducing cutaneous melanoma in animal models. Data also indicate that between a 0.3 and 6 percent increase in cataracts can be expected for every 1 percent decrease in stratospheric ozone.

### 2.5.4. *Population Settlements*

There is good evidence that alterations in human settlement patterns result from global warming and consequent shifts of rainfall patterns and deserts (Lemons 1985). Examples include: (1)the dispersal of the ancient Mycenaeans circa 1230 B.C.; (2)abandonment of agricultural areas and villages in Europe circa 1450 due to severe winters and variable summers; (3)the Irish potato famine, which resulted from warmer and wetter than usual summers between 1845 and 1851; (4)the displacement of hundreds of thousands of farmers and settlers from the western North American plains due to drought in the 1890s and 1930s; and (5)recent deaths and resettlement of nomadic populations during the Sahelian drought of 1968-73.

The adverse effects of climate change will disproportionately affect the people of developing countries, since it is estimated that they will comprise about 78 percent of the world population in the year 2000, and because they utilize marginal lands that are more susceptible to climate change for their livelihood (UNPF 1991). Of course, one of the most catastrophic impacts would result from the disintegration of the unstable West Antarctic ice sheet, should this occur. For example, estimates are that in the United States alone 11 to 16 million people would be displaced (Bentley 1980); 8 to 12 million people could be displaced along the Nile River delta (El-Sayed 1991).

Although the historical evidence indicates the significant impact of increased regional warming upon human settlements, it is not feasible to make detailed predictions of the effect of future warming for many regions because changes in regional temperature and precipitation variability cannot be ascertained at this time.

### 2.5.5. *Agriculture, Livestock, and Fisheries*

The stability and distribution of food production could be affected greatly by climate warming, in terms of both agricultural productivity and trade (Dudek 1991). Changes in the world food system will be due to: (1)direct biological effects of increased carbon dioxide concentrations, which would tend to increase productivity; (2)interactions of temperature and precipitation in rainfed agriculture; (3)changes in water demand and availability for irrigation; (4)longer growing seasons in temperate latitudes; (5)changes in soil nutrients and salinity; (6)increased infestations of agricultural pests and diseases; (7)stress on livestock production; and (8)the exacerbation of water and air pollution problems by climate warming. Although the causal mechanisms resulting in changes in the world agricultural system due to climate change are known with some confidence, the directions and magnitudes of some of the changes are not known well for at least four reasons.

First, as discussed previously, the likely changes in variability of temperature and precipitation for specific geographical regions are not known. Second, every crop responds to climatic factors differently, and effects must be examined individually. For example, estimates are that a 1°C. temperature increase results in a 2 percent reduction in U.S. corn yield or a 12 percent reduction if combined with a 10 percent reduction in precipitation; other projections indicate that wheat yields would increase (Waggoner 1983). Third, changing climate affects the frequency and severity of food pest infestations. Pimentel (1989) indicates that warmer and longer growing seasons induced by climate change could enable many insect pests to pass through an additional one to three generations. The exponential increase of some pest populations under new favorable environments could increase losses due to insects and make their control more difficult. Fourth, economic dislocations due to climate change limit food availability and distribution. Most food traded is surplus, and yearly weather fluctuations affect the amount of surplus and demand for it. These fluctuations create wide price swings, which influence local supplies and the ability of people to afford them.

Chameides et al. (1994) have examined possible implications of regional ozone pollution for the three most agriculturally productive regions of the world. These regions cover 23 percent of the earth's continents but account for most of the world's energy consumption, fertilizer use, food-crop production, and food exports. They also account for more than half of the world's atmospheric nitrogen oxide emissions. As a result, they are prone to high levels of ground-level ozone during summer months. Approximately 10-35 percent of these agriculturally productive regions currently may be exposed to levels of ozone that may reduce crop yields. If abatement of anthropogenic nitrogen oxide does not occur, by the year 2025 approximately 30-75 percent of the world's cereals may be grown in ozone-damaging regions. This could result in a 5-10 percent reduction in crop yields.

Recent models have been used to calculate population size, food production and consumption, and storage of grain under different climate scenarios over a 20-year period (Daily and Ehrlich 1990). According to results of this modeling, it is possible that there will be a 10 percent reduction in global grain harvest an average of three times a decade. This could result in the starvation of between 50 and 400 million people. Further, global warming could reduce cropland by 10 to 50 percent due to increased temperatures, increased rainfall in certain areas, and coastal flooding. Developing regions whose agriculture appears to be at most risk from climate warming include the Sahel, Egypt, southern Africa, India, eastern Brazil, and Mexico (IPCC 1990, Parry 1990).

The IPCC (1990) recognizes three primary areas of uncertainty that need to be resolved to understand the responses of agricultural systems to climate change: (1)understanding the effects of climatic and atmospheric changes, singly and interactively, on major crop, forest, and livestock species; (2)understanding how pests and diseases will change in impact, spatial and temporal distribution, and variability, and to model these changes so that they may be incorporated into change and management scenarios; and (3)development of the capacity to predict the effects of changes in climate and atmospheric composition on the quality of land through changes of *in situ* soil processes and in soil erosion.

Supplies of fish are important to many countries for economic reasons and as a protein source, and some studies have noted the effect of temperature changes on fisheries resources. For example, the periodic reduction of oceanic upwelling due to coastal and surface water warming and the consequent nonreplenishment of nutrients to surface waters has caused declines of fish catches off the coasts of Peru, California, Namibia, Somalia, and Mauritania (Ryther 1969). These regions contribute a significant fraction of the world's fish supply. Although there is some understanding of how temperature fluctuations can affect net fish productivity, other climatic and oceanic variables such as prevailing winds and ocean currents, cloud cover and rainfall patterns, and availability of nutrients also influence production. Because it is not known how all of these might change as a result of climate warming, it is not yet possible to predict impacts to fisheries accurately.

### 2.5.6. *Water Resources*

Climate warming will alter precipitation, both globally and regionally. Potential sensitivity of water resource issues to global warming determined from GCM sensitivity analysis includes inadequate surface water supply/storage, groundwater mining, flooding, conflicts in water use, salinity problems, drought, water for vegetation, surface water contamination, waterborne diseases, inefficient irrigation management, availability of potable water, and reservoir sedimentation. However, researchers disagree considerably about the levels of confidence that should exist regarding predictions of climate change on water resources. Recent estimates suggest that 10-50 years are needed before predictions can be made with confidence (Schneider et al. 1990).

Typically, climate models project that the largest changes in precipitation will occur in the vicinity of 30°S and 30°N (Sulzman et al. in press). Increased precipitation at higher latitudes is expected throughout the year, and at midlatitudes during winter months. Many models project little change in precipitation for the dry subtropics. Other models that project geographic distributions of hydrological changes show different responses at different latitudes. Decreases in precipitation are predicted to occur between latitudes 40°N and 10°S, while increased precipitation is expected to occur between 10°N and 20°S in regions north of 50°N and south of 30°S (Washington 1992). Such changes would have profound effects on the distribution of the world's water resources. The combination of increased evaporation and decreased rainfall in the Colorado River system of the United States would diminish the flow of the river by 50 percent or more. Other river systems that provide needed water for prime agricultural areas and that would experience greatly increased flows include: the Hwang Ho in China; the Amu Darya and Syr Darya in Asia; the Tigris-Euphrates system in Turkey, Syria, and Iraq; the Zambezi in Zimbabwe and Zambia; and the São Francisco in Brazil. Increased water flows resulting from increased precipitation could occur in the northern Africa rivers of the Niger, Chari, Senegal, Volta, and Blue Nile. Projected increased flows in the Mekong and Brahmaptura rivers could lead to widespread and destructive flooding in Thailand, Laos, Cambodia, Vietnam, India, and Bangladesh.

Even if effects of climate change on water resources were not catastrophic, significant changes in water supply systems could still result from decreases in mean stream flow or increases in variance of stream flow. Such attributes include water quality and yield from unregulated streams, reservoirs, and groundwater. In addition, changes in storm frequency and drought are likely to be brought about by climate change. It is estimated that the destructive potential of hurricanes might increase by 40 to 50 percent with a doubling of atmospheric carbon dioxide (Hansen et al. 1989).

### 2.5.7. *Sea Level Rise*

The general effect of sea level rise is to increase beach erosion, the loss of marshes, storm damage, and salt water intrusion and to threaten the lives and well-being of people and their buildings. Because a large fraction of the world's people live in coastal zones, they are prone to the adverse consequences of even a small increase in sea level. Countries such as the Netherlands, Egypt, and Bangladesh particularly are at risk.

Average surface temperatures have risen approximately 1°C in the last century, and sea levels have increased at an average rate of approximately 1 to 1.5 mm per year during this time (Gornitz and Lebedeff 1987). Typical projections of future sea level rise range from about 0.3 m to 3.5 m by the year 2100, although some projections are greater (Hoffman et al. 1983, Meier 1990). However, it is not clear exactly how accelerated atmospheric warming will affect sea level rise because the interactions between the atmosphere and the ocean are not understood well.

Sea level rise also is a function of whether and to what extent a reduction of the amount of sea ice drifting in the Arctic Ocean occurs and whether partial melting of the West Antarctic ice sheet occurs. The effects of the former would be to increase sea surface temperature and consequently shift major climatic zones 200 km or more northward. These effects might occur over a period of a few decades if atmospheric temperature increases approach 4 to 5°C (Flohn 1982). The effects of a partial melting of the West Antarctic ice sheet might be a 5 m or more elevation rise of the world's sea level, with consequential flooding of many coastal and lowland areas. Considerable debate exists concerning the likelihood of the Antarctic ice sheet melting. Based upon paleoclimatic evidence, Flohn argues that an atmospheric warming of 4 or 5°C would result in an ice-free Arctic Ocean but would not cause significant melting of the Antarctic ice sheet. Based on data from the geologic record, Leatherman (1991) argues that melting of most of the ice in ice caps and glaciers could result in a 70-m rise in sea level, but that such melting would likely occur over a time span of millions of years.

Mitchell (1982) postulates that the paleoclimatic data are tenuous and suggests that some climate models project melting of the Antarctic ice sheet occurring over a period of 1,000 years. In theory, the advantage of using paleoclimatic analogues is that they represent realistic solutions for sets of equations that only nature can solve; main disadvantages are that changes in boundary conditions (e.g., atmospheric composition, sea level, land surface changes) over time are not known well and data resolution allowing for mapping of past climates is insufficient. On the other hand, current climate models, while projecting melting of the Antarctic ice sheet, are not sufficient to allow for reasonably accurate predictions.

## 2.6. CLIMATE LINKAGES

In order to understand global climate changes, linkages among different phenomena need to be understood. In some modeling experiments, the influence of other greenhouse gases in addition to carbon dioxide has been considered. Results from these experiments indicate that projected mean annual atmospheric temperature increases should be approximately 20 percent higher than those based on carbon dioxide concentration only (Wang et al. 1991). These results suggest that more definitive studies of climate change should use other greenhouse gases in addition to carbon dioxide. Inclusion of other greenhouse gases into climate change studies is difficult because fundamental aspects of factors that regulate their atmospheric concentrations are not well understood.

For example, although the atmospheric concentrations of greenhouse gases have been increasing, beginning in 1991 the buildup of carbon dioxide, methane, and nitrous oxide slowed. Only recently have those gases resumed their historical rates of increase. However, the buildup of carbon monoxide continues to slow (Novelli et al. 1994). Presently, researchers have not developed causal mechanisms to explain these observations. Some researchers believe that the chemistry and recent buildup of the atmospheric concentrations are related, perhaps by the eruption of Mt. Pinatubo and atmospheric cooling it may have caused. However, they have been unable to develop a coherent explanation of the role of the eruption of Mt. Pinatubo as it might have affected the recent anomalies for carbon dioxide, methane, nitrous oxide, and carbon monoxide (Kerr 1994). Other factors that have been implicated (but not proved) in causing a temporary slowdown in these greenhouse gases include a reduction in methane sources (e.g., biomass burning, rice paddies, and natural wetlands that might have slowed in a cooler climate due to the eruption of Mt. Pinatubo) and the patching of natural gas pipeline leaks in the former Soviet Union. Recent dry spells in the tropics might have affected levels of carbon monoxide due to less biomass burning because of a reduction in the amount of agricultural waste needing to be burned and by a slowed expansion of slash-and-burn agriculture brought about by dryer conditions. Researchers do not really know how to explain the rise of nitrous oxide, because it has many sources in the soil and water, and it is not known how human activity has been affecting them.

Recently, the impact of stratospheric ozone depletion on global warming has been assessed. Although CFCs are effective at trapping heat in the lower atmosphere, they are the primary source of chlorine, which degrades stratospheric ozone. There are indications that decreased stratospheric ozone may exert a cooling effect on the lower atmosphere that might offset (partially) the warming attributed to CFCs (WMO 1993). Although there are many uncertainties surrounding these estimates, if accurate, they might partially explain why observed atmospheric temperature increases lagged behind those predicted by GCMs. In essence, until these types of linkages are established, the links between climate and atmospheric composition that might amplify global warming in the future will not be understood.

In order to make more accurate projections of temperature change, the linkages of climate models with such factors as future levels and rates of fossil fuel use, emission rates of other greenhouse gases, deforestation, and population growth rates need to be established (Lemons 1985, UNPF 1991). Projections of future fossil fuel use are based on numerous assumptions concerning future rates and levels of population growth, gross national product growth rates, informational inputs for energy models such as governmental energy policies and mix of energy sources, and whether significant energy conservation is realized. Various projections of world energy use for the year 2000 have ranged between 384 and 646 quads, and between 334 and 847 quads for the year 2020. Generally speaking, high consumption scenarios are characterized by low or moderate use of coal and little or no use of oil shale. Obviously, the mix of energy fuels actually utilized will be of paramount importance to future climate change. Unfortunately, the uncertainties regarding energy use are so large that they have precluded projections of "most likely" scenarios.

The net effect of changing land use on future concentrations of greenhouse gases can be significant (Houghton and Skole 1990). Forests can serve as a larger sink for atmospheric carbon dioxide if they are increased, or they can serve as a source of additional atmospheric carbon dioxide if they are cleared. Projections of future rates of deforestation vary due to uncertainties regarding the need for agricultural land and fuel wood, a sustained demand for wood operating in the absence of effective programs for forest conservation, population growth rates, and increases in standards of living. Typical rates of deforestation have been projected to range between 4 and 20 million hectares per year through the end of the century (WRI 1992). Estimates of the release of carbon from deforestation over the past decade have ranged from between 20 and 100 percent of the annual emission of carbon from fossil fuels (Woodwell et al. 1978), although a figure of about 20 to 30 percent commonly is accepted (Houghton 1991).

The emission of greenhouse gases is linked to population growth (Harrison 1990). During the period 1950-1985, worldwide emissions of carbon dioxide increased an average of 3.1 percent per year. During the same period, population growth grew by 1.9 percent per year, and per capita production of carbon dioxide increased 1.2 percent per year. Presumably, this latter increase was due to the higher per capita consumption of goods that involved the production of carbon dioxide. According to this type of analysis, population growth was responsible for approximately two thirds of the increase in carbon dioxide emissions during this 35-year period.

If carbon dioxide emissions in developing countries increase at the same rate that they have during the past 40 years, they will more than double from the 1985 level of 0.8 to 1.7 metric tons on a per capita basis by the year 2025. During this time, the populations of these countries are projected to almost double from 3.7 to 7.2 billion people. The increase in population would produce an additional 5.8 billion metric tons of carbon dioxide compared with the present worldwide total of about 6.9 metric tons. To be sure, this type of analysis is subject to uncertainty for a variety of reasons. For example, it implies a linear progression of consumption patterns and trends and does not reflect the fact that economic processes are subject to nonlinear changes.

The linkage between population growth and greenhouse gas emissions can, perhaps, best be exemplified by India. During recent years, the government of India has developed a number of initiatives to promote economic development and improve living standards. It is projected that this development will induce a doubling of India's carbon dioxide emissions (Dave 1988, Oppenheimer and Boyle 1990). More to the point, consider that India's 1990 population of about 850 million people is growing at the rate of about 2.1 percent per year and is projected to increase by 1.4 billion people by 2024. If we assume that India manages to reduce its fertility rate to replacement level within the next three or four decades and if it only doubled its per capita use of energy by use of fossil fuels, given the multiplier effect of India's present population and its rate of growth, the annual per capita emission of carbon dioxide in 2024 would be about one metric ton, which is the 1990 world average. Because of the multiplier effect of population, this increased amount of carbon dioxide emitted would more than cancel stringent reductions of carbon dioxide emissions made elsewhere. For example, it would exceed the reduction in carbon dioxide emissions if the United States stopped all coal burning without replacing it with any other fossil fuels (Ehrlich and Ehrlich 1990).

Assessing the linkages between population growth and greenhouse gas emissions becomes more problematic when other gases such as methane are considered. Methane is a potent greenhouse gas, and half of all anthropogenic emissions come from rice paddies, irrigated lands, and ruminant livestock. These sources have expanded in recent years to meet the needs of increasing populations and because of the demand for improved diets. About 14 percent of greenhouse gas emissions are from agricultural sources, and the overall amount can be expected to increase as more food is required to feed an expanding human population. While the argument can be made that some carbon dioxide emissions should be reduced because they result from inefficient patterns of production and consumption, this argument is not made easily in the case of methane, because some of its production is tied to food to support an expanding human population.

Some researchers have made projections of future atmospheric temperature increases by taking into account the scientific as well as other uncertainties such as future energy use. Using carbon dioxide emissions from fossil fuel combustion as an example, traditional thought is that the future growth of atmospheric carbon dioxide should depend primarily on the rate of fossil fuel combustion and the manner in which the carbon cycle responds to the increased carbon dioxide (Baes et al. 1976). Assuming a high-energy-use scenario whereby the initial growth rate of fossil fuels is 4.3 percent per year (and which is reduced in proportion to the fraction of the supply of fossil fuel that has been used), various models predict more than half of the 7,000 Gt of recoverable fossil carbon will be released in less than 100 years. This represents a predicted range of temperature increase of between 2°C to 10°C and 2.5°C to 12.5°C. (Two minimum and maximum temperatures are given, which reflect uncertainties in the behavior of the carbon cycle, extent of deforestation, etc.) If a low-energy-use scenario is assumed, where the fossil fuel growth rate is only 2 percent per year until the year 2025 (followed by a symmetrical decrease as solar energy becomes more available and fossil fuel use is discouraged), the models predict that the total carbon released will be about 25 percent of the high-energy-use scenario and that the carbon dioxide content of the atmosphere will be approximately 1.5 times preindustrial levels. Projections for this scenario indicate a temperature increase between 0.5°C to 2.5°C and 1.0°C to 5.0°C. If present fossil fuel emission levels continue unchanged, doubling of carbon dioxide does not occur until into the 23rd century. In contrast, an annual fossil fuel growth rate of 4.3 percent would double atmospheric carbon dioxide within the lifetime of today's children (Clark 1982). Significant environmental impacts have been predicted if the globally averaged temperature increases by approximately 3°C to 4°C; such an increase is projected if atmospheric carbon dioxide concentration increases to approximately 500-620 ppm. Assuming even moderate world economic growth and world fossil fuel energy increases of 2 to 3 percent per year, the estimated atmospheric carbon dioxide concentration would be approximately 580-650 ppm by the middle of the next century or before (Washington 1992).

When considering the effects of climate change, it also is important to remember that extremes, variability, and means of climate conditions will affect the severity of other environmental problems such as acid deposition, stratospheric ozone depletion, and attainment of ambient air pollution standards (White 1989). For example, the amounts of sulphur dioxide and nitrogen oxides are influenced by climate in their source regions. Cold winters increase demands for heating oil in some regions and therefore the production of nitrogen oxides. Warmer summers increase demands for electricity and therefore the production of sulphur dioxide if coal is used as an energy source. Emissions of carbon monoxide, nitrogen oxides, and volatile organic compounds stemming from transportation use are influenced by the effect of weather on combustion efficiency. Warming of the atmosphere also will increase the transformation rates of primary acidifying gases and the production of ozone. This change in transformation rates will lead to a change in the relative amounts of acidifying materials deposited and in their concentrations.

Land-use and resource policies will affect and be affected by changes in the atmosphere. Policies that affect the quality of terrestrial and marine resources can decrease greenhouse gas sinks and increase atmospheric emissions. Loss of biological diversity may reduce the resilience of ecosystems to climatic variations and to air pollution damage. Climate change and agriculture may affect the natural environment due to regional changes in crop and livestock production. Changes in agriculture may increase soil erosion, intensify the demand for water for irrigation, degrade water quality, reduce forested land, and impact wildlife habitat. The problems of population growth and the human demands on natural resources also will be exacerbated by consequences of climate change. For example, within another few decades Bangladesh may lose a sizable portion of its land to sea-level rise, but by that time its population is projected to increase to twice its present level of 116 million people (Meyers 1993).

All of these types of linkages introduce many more uncertainties into the assessment of future impacts of climate change in addition to those described already.

## 3. Ethics and Climate Change

The possibility of climate change poses many ethical issues. These include questions about global environmental justice, duties to future generations, duties to nonhumans, our obligations as individuals, and what constitutes ethical national policies. In addition, questions in these areas interact with science and economics. How do we make morally responsible decisions under conditions of ignorance or scientific uncertainty or when facts are indeterminate? How do economic considerations relate to moral reasons? We cannot hope to answer these questions here. Instead, we will provide an introduction to some of the most important ethical issues posed by anthropogenic climate change.

### 3.1. GLOBAL ENVIRONMENTAL JUSTICE

Questions about global environmental justice take on their meaning and significance against an empirical background. Primarily it is the industrial or materially rich countries that have loaded the atmosphere with greenhouse gases. The fact that they are rich is closely related to their use of fossil fuels in key stages of their development. While the rich countries have reaped private benefits from emitting greenhouse gases, the negative effects of these emissions will be felt by people all over the world, including those who did not benefit from the economic development that the massive use of fossil fuels made possible. For example, the people of Bangladesh have benefited very little from the large-scale use of fossil fuels. Yet some projections suggest that climate-change-induced floods may kill or harm hundreds of thousands of Bengalis (IPCC 1990).

Inequities in the emissions of greenhouse gases are not only historical facts. A handful of industrial countries still emit between one half and three quarters of all greenhouse gases (Brown et al. 1994). Furthermore, despite frequently stated worries about potential increases of emissions in the developing world, the annual increases of greenhouse gas emissions is greater in the United States than it is in India (IPCC 1990).

Inequities in greenhouse gas emissions are part of an international system that is characterized by increasing inequality. Tickell (1992) states that in 1880 the real per capita income between Europe on the one hand and India and China was 2 to 1; by 1975 it was 40 to 1, and now it is 70 to 1. According to the World Bank (1992), poverty is increasing; there are now 1.1 billion people living in poverty, more than 20 percent of the world's population. Yet resources continue to be transferred from poor to rich countries. George (1992) says that between 1982 and 1990, rich countries sent about $900 billion to poor countries in the form of loans, credits, and grants, while during the same period, poor countries paid more than $1.3 trillion to rich countries in interest and principal payments on loans.

In the background are problems of overpopulation and overconsumption. Despite efforts such as the 1994 Cairo conference on population, global population is expected at least to double from what it is at present before stabilizing, and even this may prove to be an optimistic expectation. Most people in the rich countries show little inclination to stabilize consumption, and many people in the poor countries would like to increase their rate of consumption. One way of understanding the possible impacts of the conjunction of growth in population and per capita consumption is to consider the following example. Sweden enjoys a high quality of life, yet its greenhouse gas emissions are only 40 percent of those in the United States on a per capita basis. If global per capita greenhouse gas emissions were the same as Sweden's, global emissions would more than triple, reflecting the large populations and low emissions of some underdeveloped countries (Streets 1990). This tripling of emissions is beyond even the worst scenarios that have been contemplated in most studies.

In the face of these profound problems, philosophers have had little influence. Indeed, there has been some question about whether questions of justice (as opposed to obligation) arise at all in international relations. Even if we assume (as we should) that these questions involve matters of justice, it is difficult to see how traditional theories of justice apply to them. The most influential theories of justice in the contemporary literature are those that center on equality and those that focus on entitlements. These theories provide precise formulations of two of our deepest intuitions about justice. The egalitarian intuition is that everyone should have the same. The entitlement intuition is that everyone should have what they deserve.

The most influential egalitarian theory is Rawls's (1971) theory of justice. According to Rawls, fair principles of justice are those that would be chosen by agents in the "original position," in which they do not know their particular tastes, preferences, or place in society. Rawls thinks that these agents would reject the idea of absolute equality (in itself a very difficult idea to formulate) and choose instead two lexically ordered principles, the first concerning liberty and the second concerning distribution. The second principle (the "Difference Principle") requires social and economic inequalities to be attached to positions and offices that are open to all under conditions of fair equality of opportunity and that they be to the greatest benefit of the least advantaged members of society.

The most influential entitlement theory is that of Nozick (1974). He argues that the justice of a distribution depends entirely on how it was arrived at, no matter how equal or unequal it may be. According to Nozick, a complete theory of justice is comprised of three principles: a principle of just acquisition, a principle of justice in transfer, and a principle for rectifying past injustices.

On the face of it, it would appear that both theories imply that the present international order is unjust. Clearly, the inequalities that exist do not benefit the disadvantaged, and in part the present distribution reflects the global history of domination, imperialism, and exploitation. Yet Rawls and Nozick have little to say about international and environmental justice. Moreover, many environmental goods appear to resist treatment as distributable benefits and burdens (the stuff of distributive justice). We are situated in an environment that conditions everything we do and that in part constitutes our identities. Furthermore, on any reasonable human time scale, a stable climate, unlike standard commodities, is irreplaceable (Jamieson 1994).

While it is plausible to suppose that both historical and present patterns of greenhouse gas emissions are part of an unjust international order, philosophical theories of justice thus far have provided only limited conceptual resources for dealing with these problems.

### 3.2. FUTURE GENERATIONS

Our contemporaries are often victims of injustice, but there are mechanisms for representing their interests. These range from systems of justice in individual countries to the United Nations. Those who come after us are likely to live in a very different world from what they would have due to the climate change that we may be bringing about. Yet future people have no representation in the deliberations of today.

That future people have no political representation is an obvious fact. They cannot vote, and there are presently no trustees who are charged to defend their interests (Weiss 1988). A more complicated question concerns the representation of future interests in present economic decisions.

It is common practice in economic decisionmaking to discount future costs and benefits. There are both good and bad reasons for such an approach. The good reason is that if we undertake a project now that will entail a cost of $N$ in 10 years, the project will be worth doing if the present benefits invested for 10 years will equal or exceed the cost. But this approach becomes problematical in cases in which there is uncertainty, irreversibility, or uncompensable harms.

Suppose that our present climate change activities will result in damages of $N$ for our descendents living in a century. If we can obtain a 5 percent return (compounded monthly) on present benefits, our climate change activities would only have to be worth $.0068N$ in order for them to be justified. For example, a present benefit of $100,000 would justify inflicting a cost of $14.68 billion on those living a century hence. Not only does this specific result seem suspect, it seems ludicrous to suppose that we can do the calculation at all, for that would require assigning meaningful economic values to the loss of many wild species, the destruction of societies and cultures, and the unknown health effects of climate change. But even if these problems could be overcome, we would still be faced with the moral issue of climate change depriving future people of significant choice. They might prefer to live in a world characterized by our current stable climate regime rather than to enjoy a higher standard of living.

One line of argument suggests that present people owe nothing to future generations (Schwartz 1978). Since the actions we undertake now will determine which future individual people will come to exist, nothing we do now will make future individuals worse off than they otherwise would have been. Thus no future person can complain that he or she would have been better off had present people made different choices; had our choices been different, the person with the complaint would not have existed at all.

In our view, the moral of this argument is not that present people are ethically absolved of the effects of their actions on the future, but rather that actions can be wrong even if no individual is made worse off. This is an important result, for it compels us to reject some otherwise plausible, person-affecting moralities, and perhaps the view that intergenerational morality is a matter of justice or rights (MacLean 1983).

The utilitarian tradition has claimed the other extreme. Sidgwick (1907) argued that impartial morality requires that the time someone exists has no relevance to the urgency of that person's interests. To value the interests of future people less because they are remote in time from us is as morally arbitrary as discounting the interests of people who are remote from us in space, ethnicity, or psychological constitution. While this is a powerful argument, it seems to have the consequence that the interests of present people will always be swamped by those of future people. If large human populations continue to exist for, say, a million years, the interests of those living now will inevitably lose to those who will come after. There are vastly more of them than there are of us.

Once again we must conclude that an important moral problem has not been solved, even in theory. Most of us believe that we owe something to the future but not as much as to the present. This intuition may be correct, but as of yet it suffers from a lack of secure philosophical grounding.

## 3.3. NONHUMANS

Future people are not adequately represented in present decision processes, but at least they will be represented when they become decisionmakers; nonhumans are not represented at all, yet the effects of climate change on the nonhuman environment may be even greater than on humans. Climate change is likely to be much too rapid for many plants and animals to migrate or adapt. Even when migration would in principle be possible, few migration routes will be available in an environment that has become highly fragmented due to widespread and densely populated areas. Despite the intensity of these impacts, nonhuman nature is completely without representation in our decision processes. It must depend entirely on the preferences of human sympathizers for support.

Of course, some people would say that nonhuman nature is not entitled to moral consideration because, they say, it has only instrumental value and therefore serves as "raw material" for us to use as we please. This view has been criticized in recent years (see, e.g., Gruen and Jamieson 1994). Singer (1975/1990) has argued that we have moral obligations to all sentient creatures. This would include many nonhuman animals, such as other mammals. Goodpaster (1994) and Taylor (1986) have argued that we have moral obligations to every living thing. Rolston (1988) has argued that we have obligations to virtually every element of the natural order, including whole species and ecosystems.

If any of these views are correct, then climate change poses serious moral problems with respect to our obligations to nonhuman nature. Our usual approach, to consider the value of nature to be the value that humans place on nature, simply will not do. If nature is entitled to direct moral consideration, then it would be as wrong to think that the value of nature is exhausted by "contingent evaluation" as to think that this approach exhausts the value of children, the aged, or any other human.

## 3.4. ETHICS AND ECONOMICS

Thinking about ethical issues relating to climate change is difficult for many reasons. One complexity concerns the relations between ethics and economics.

Economic analyses and evaluation often work in two distinct ways. In one way they are hypothetical. They tell us what the economic implications are of various courses of action. Such analyses and evaluation provide one important piece of information, but in themselves they do not tell us what to do. Economic values are not the only values, and often we think that it is right for someone to do something that makes little economic sense. For example, most of us would say that someone who chose her friends or lovers strictly on the basis of economic considerations has an inadequate, one-dimensional value system. However, while economic analyses often begin as hypothetical, they often quickly turn to the categorical. That something makes economic sense is too often regarded as a decisive reason for action. The appropriation of such words as *rational* and *efficient* (as well as *good* and *bad*) by economists has contributed to the conflation of hypothetical and categorical evaluations.

However, once economic and moral reasons are clearly distinguished, there is a tendency to veer to the other extreme and to suppose that they have nothing to do with each other. One tradition in moral philosophy, deontology, often seems to suppose that right actions are those that are in conformity with moral rules, regardless of the consequences, economic or otherwise (see e.g., Bennett 1981). But surely this cannot be entirely right. Certainly we need to construe the consequences of actions or policies in a way that is much broader than is typically done in economic evaluation, and perhaps even then the consequences may not in themselves be a decisive reason for undertaking the action or policy. However, it is quite implausible to deny that consequences should play an important role in the evaluation of actions and policies. It may generally be wrong to lie, but if the entire fate of the world hangs on someone lying, then surely she should lie.

Economic results are an important consequence of many decisions, and therefore it is often important to know what they are. The possibility of climate change poses many important moral questions, but they are not completely separable from economic considerations. What we need to understand clearly is that moral considerations are not exhausted by economic concerns. What this means in the case of abating emissions of greenhouse gases is that while the costs and benefits of doing so are important to assess, the policy decision about whether or not to abate should not be decided solely on economic grounds.

## 3.5. SCIENTIFIC UNCERTAINTY

Policy decisions about climate change are made even more difficult by the problem of scientific uncertainty. Uncertainty often provokes people to divide into two camps. One camp insists that no action be taken until more research is done. The other camp claims that enough is known to take some action now. These arguments often have the effect of delegitimizing science in the eyes of the public, which sees science being brought in to provide justifications for policy decisions that are really being made on other grounds. In order to understand better the problem of trying to determine how much knowledge is enough for action to be warranted, it is important to make some distinctions and to appreciate the social context in which questions of uncertainty arise (Wynne 1992).

First, consider the distinction between uncertainty and ignorance. When we say that we are uncertain of something, this suggests that we know what it would take to make us certain. Ignorance, on the other hand, relates to the fact that we could be wrong about almost any proposition to which we give our assent and in many cases have no reasonable way of assessing this probability. However, from the fact that we could be wrong about almost anything, it doesn't follow that we are uncertain about almost everything. We can say crudely that uncertainty arises from ignoring ignorance. We take various features of a problem as given and focus on other dimensions. For example, it is widely agreed that the case for climate change is weakened by the fact that we are uncertain about the effects of clouds on the climate system. To identify clouds as an area of uncertainty is to presuppose that our general knowledge of the climate system is largely correct. This general background knowledge is "black-boxed"; it is taken as a set of fixed assumptions from which we proceed. This process of black-boxing is part of what makes science possible, for not every proposition can be interrogated simultaneously.

Uncertainty also needs to be distinguished from indeterminacy. Often what appears to be uncertainty cannot be reduced because there is no fact of the matter that can be learned that will reduce the apparent uncertainty. There is a great deal of indeterminism in the climate change debate because we do not know how people will behave in the future—what policy decisions governments will undertake, what firms will do, how individuals will change their lifestyles, and so on. There is no uncertainty about these matters because there are not now any facts about which we can become more certain. A second source of indeterminacy flows from the fact that any piece of data is evidence for a multiplicity of distinct hypotheses (Quine 1960). This is why different people with varying worldviews can feel vindicated by one and the same experience.

Once these distinctions have been made, we can see that regarding some proposition as uncertain is already to make some very large assumptions. Various problems about ignorance and indeterminacy have been pushed aside. Large social forces as well as small scientific ones can be involved in this pushing aside.

When we say that something is uncertain, we are relating it to a purpose. Some people claim that it is uncertain whether emitting greenhouse gases into the atmosphere will change climate; others seem to deny this. But in some cases they are not really disagreeing. Both parties may agree that for the purposes of scientific knowledge more research is needed. But those who deny that there is significant uncertainty may be claiming that there is no uncertainty for the purposes of policy formation, that what we ought to do is clear.

We should recognize the rhetorical role of claims of uncertainty. Often such claims are a way of arguing that no action should be taken. Those who want to take action then feel compelled to claim that there is no significant uncertainty. A debate that is really about values is disguised as a discussion of epistemology. In our view it would be better to discuss our ethical differences explicitly and directly rather than to mask them in the language of science (Jamieson 1992).

## 3.6. ETHICAL NATIONAL POLICY

While we have raised more questions than we have provided answers, still something can and should be said about what constitutes ethical national policy with respect to climate change.

The first point to make is that just as a policy should be based on good science and in some sense be economically reasonable, so a national policy should be responsive to the ethical concerns that we have identified. Second, it should be clear that ethical national policies will be different for different countries. For the United States to continue to increase dramatically its emissions of greenhouse gases is unethical in a way in which it is not for India or Haiti. Indeed, an ethical policy for the United States will be different from such a policy for other industrial countries, given their different histories, access to resources, alternatives, and so on. The framework for an ethical policy is established in part by the network of agreements to which a nation is party. The United States, along with more than 160 other countries, is committed to stabilizing greenhouse gas emissions. Exactly what this means remains a matter of negotiation and commitment, but the direction of change is clear.

What more an ethical policy would require depends on how one weights the various considerations that we have identified: global environmental justice, duties to future generations, obligations to nonhuman nature, and so on. However, it does seem clear that an ethical policy probably requires more than the United States is currently doing to reduce greenhouse gas emissions. Even a reasonable regard for the nation's long-term self-interest would seem to require more. While it is often argued that the developing countries are more likely to suffer serious adverse impacts from climate change than the developed countries, still the developed countries should be more risk-averse because they also will experience significant losses. A prudent government will protect a rich nation from what may be a serious risk. Moreover, it seems clear that the United States would benefit from reducing to some degree its use of fossil fuels. Energy in the United States is currently being used inefficiently compared with most European countries, and in addition to the direct economic effects of such inefficient uses, it also indirectly results in air and water pollution, land disturbance, and congestion and also makes the United States strategically dependent on the Middle East.

While it is unclear exactly what range of policies would constitute an ethical national policy for the United States with respect to climate change, it is clear that this range of policies would more effectively reduce the use of fossil fuels than those currently in place.

### 3.7. INDIVIDUAL RESPONSIBILITY

Whatever policy a nation adopts with respect to climate change, individuals are not thereby freed from acting in a morally responsible way in their everyday lives. Part of what it means to act in a morally responsible way is to work for political and other collective solutions to public problems. But it also means adopting lifestyles that are themselves ethically responsible. With respect to climate stabilization, this means reducing both the use of fossil fuels and engagement in other activities that promote the release of greenhouse gases. Changing lifestyles can be effective both in their cumulative effects and as one way of trying to bring about political and social change. If decisionmakers see that people are willing to change their behavior in the absence of coercion or legal mandates, this can help give the decisionmakers the courage to adopt ethical national policies. But even if societies do not change their behavior and a destructive climate change occurs, morally responsible individuals will at least have the satisfaction of knowing that they did what they could in a time of decision. They were a part of the solution, not just a part of the problem.

## 4. Greenhouse Economics

The contribution of economists to the greenhouse debate can be broadly divided into determining how seriously the threat needs to be taken and what action is most efficient to achieve agreed-upon policies. The first area is the realm of cost-benefit analysis and modeling intergenerational welfare. The second concentrates upon alternative policy instruments such as carbon taxes versus tradeable pollution permits and the impacts of different tax structures on various industrial sectors. The majority of economists are far more comfortable with this latter role, because the tools of conventional economics can be applied and many of the existing models developed for other purposes can be used—for example, merely by changing one sector to represent energy production or increasing the price of fossil fuel inputs. Hence trade, optimal control, and game theory models have been repeatedly applied in the economic literature on global warming. However, this second area of research also works within the framework set up by the first and must accept the theoretical approach that is common to both, in particular the utilitarian philosophy and trade-off assumptions. Thus, while the following sections concentrate on cost-benefit analysis and intergenerational issues, the constraints to economic techniques that are identified have broader implications. In the next section, the cost-benefit analysis approach is outlined and critically analyzed. A comprehensive treatment of cost-benefit analysis in the environmental context is given by

Hanley and Spash (1993). The discussion here raises the issues of uncertainty, individual preference formation, and intergenerational ethics, each of which is dealt with in turn.

## 4.1. COST-BENEFIT ANALYSIS OF GREENHOUSE GAS CONTROL

The movement toward the adoption of a cost-benefit analysis approach to this issue can be seen on at least two fronts. First, legislation concerning public projects has become increasingly environmentally concerned because of a publicly recognized need to conserve scarce resources. Current legislation in Europe requires the use of environmental impact assessment (where impacts are measured in physical units) for certain projects, under Directive 85/337. While cost-benefit analysis is an alternative paradigm for measuring environmental impacts, in the United States, environmental impact assessment was followed chronologically by Reagan's Executive Order 12291, mandating the use of cost-benefit analysis for public projects and policies. Hence, cost-benefit analysis has been more commonly applied in the United States, so influencing the economic literature and the policy debate on global warming. Second, the imposition of greenhouse gas constraints and/or alternative technologies in developing countries will need some justification. Preventing development projects because of their adverse impacts on global climate may disproportionately affect the economies of less developed countries, who can rightly point out that developing countries increased their own greenhouse gas emissions levels during early industrialization.

Faced with the threat of global warming, society has three options: do nothing, prepare to adapt, or reduce emissions of greenhouse gases. The first implies that the greenhouse effect is either unimportant or beneficial. The second and third options take the problem seriously enough to warrant action and could be carried out simultaneously. Adaptation would include measures such as strengthening sea defenses, changing cropping patterns, organizing population migration, and increasing irrigation. A policy solely relying on adaptation implies that humans have the ability to adapt to all future consequences and to offset undesirable physical effects and that this option is less costly than control. Irreversible damages, uncertainty, and ignorance of future consequences argue in favour of controlling greenhouse gases. However, to the extent that global warming is already irreversibly underway, society has no choice but to adapt. The third option is the one most commonly studied by economists and is the one we concentrate on here.

The economic approach to deciding how serious the problem is and what action to take involves weighing the costs of control against the benefits of preventing damages. Global warming could be reduced by cutting greenhouse gas emissions and/or by increasing sinks for the gases (e.g., reforestation). A stream of costs and a stream of benefits are associated with such actions. Optimal levels of greenhouse gas reductions could, in principle, be deduced from an examination of how costs and benefits of control vary with the level of reduction. Control costs will be higher the greater the reductions in emissions are and the faster a given reduction is attempted. The marginal benefits of reducing greenhouse gases will fall with the level of control, since fewer damages are avoided per unit of greenhouse gas reduced. The optimal level of control will occur when the marginal benefits of greenhouse gas reductions, in present value terms, are just equal to marginal control costs. If the assumptions concerning control costs and benefits are correct (e.g., there are no discontinuities in the functions), this analysis implies that the optimal reduction in greenhouse gases will be less than 100 percent, since the output associated with greenhouse gas production is valued more highly the scarcer it becomes.

The earliest example of a cost-benefit analysis of greenhouse gas control is d'Arge (1975), with little work since then until the early 1990s (a notable exception is Cumberland et al. 1982). Recent approaches range from the country-specific (Ingham and Ulph 1991) to world models (Manne and Richels 1991) and from partial equilibrium (IEA 1989) to general equilibrium studies (Bergman 1991). Surveys of this work may be found in Hoeller et al. (1991) and Ayres and Walter (1991). The almost exclusive focus of these studies is the control cost of carbon dioxide reductions with exceptions such as Nordhaus (cited below) and Cline (1992).

The work of Nordhaus (1982, 1991a, 1991b) is well known and worth analyzing more closely to convey the general cost-benefit analysis approach and some of its flaws. In his most recent studies, Nordhaus divides the U.S. into three sectors by susceptibility to climate change: (1)very susceptible, such as agriculture; (2)medium susceptibility, such as construction; and (3)unsusceptible, such as finance. These sectors accounted for 3 percent, 10 percent, and 87 percent respectively of U.S. Gross National Income (GNI) in 1981. The economic benefits of emissions reductions in the high and medium sensitivity sectors is slight (only 0.25 percent of GNI, or $6.23 billion for double carbon dioxide-equivalent), because these account for a low proportion of total GNI. Marginal damage costs under three scenarios are $1.83/ton carbon dioxide for low damages (0.25 percent of GNI), $7.33/ton for medium damages (1 percent of GNI), and $66/ton for high damages (2 percent of GNI). Nordhaus excludes undesirable effects of global warming on nonmarketed resources (such as wildlife), viewing such impacts as too difficult to value. However, he states, "My hunch is that the overall impact upon human activity is unlikely to be bigger than 2 percent of total world output" (Nordhaus 1991a). In calculating control costs, he assumes greenhouse gas reductions will be achieved by methods offering the lowest control cost. He argues that control costs will depend on how fast reductions in greenhouse gases are required and that marginal control costs will increase steeply beyond a 10 percent reduction. Thus, Nordhaus calculates the optimal control policy for the greenhouse effect as being to cut CFCs by 9 percent and carbon dioxide by 2 percent under the medium damages scenario (assuming a 1 percent discount rate).

Such minimalist recommendations have been criticized as misleading, for example by Daily et al. (1991) and Ayres and Walter (1991). The latter make three main points. First, up to a certain point, the costs of reducing greenhouse gases are negative. In other words, society would be better off reducing its use of substances generating greenhouse gases. This principally means cutting energy demand, since energy production and consumption comprise the single largest source of greenhouse gases. There are two reasons for this conclusion: (1)due to market distortions, energy is currently overused, and (2)profitable opportunities for energy conservation exist but are currently ignored. Ayres and Walter provide case-study evidence for Italy and the United States, while Fitzroy (1992) cites similar evidence produced by Flavin and Lenssen (1990). Thus, some greenhouse gas emissions can be cut at no net cost. This implies, *ceteris paribus*, a higher optimal level of emission reduction than the case where control costs are always positive.

Second, cutting greenhouse gas emissions has environmentally beneficial side-effects in addition to reducing global warming. CFC reductions will help reduce stratospheric ozone depletion. If a carbon tax were imposed, coal consumption would be cut, since coal would face a higher tax rate than either oil or natural gas due to its relatively high carbon content by weight. Reduced coal use would reduce sulphur dioxide emissions and so lower acid deposition. Substitution of renewable energy sources for fossil fuels would reduce pollution externalities. In general, fossil fuels are associated with dispersed temporal and spatial chemical impacts, while renewable energy sources tend to have local physical ones, i.e., lower external costs (Spash and Young in press). Afforestation would generate a stream of nonmarket amenity benefits, depending on the type of forestry planted. In fact, the UK Forestry Commission now includes carbon absorption benefits when appraising new tree planting (Whiteman 1991).

Finally, Nordhaus extended his estimates for the U.S. economy to the world level (as does Cline 1992), and Ayres and Walter target their criticism at these world figures. As d'Arge and Spash (1991) have pointed out, developing countries are more susceptible to global warming, with extensive dependence on climate-sensitive production, a limited ability to adapt, and a sizable population of subsistence farmers. In criticizing Nordhaus, Fitzroy (1992) points out that climate change combined with soil erosion in food-producing regions would reduce world food supplies at a time when the world population will have doubled. Declining levels in major world aquifers would aggravate this situation. Ayres and Walter revise Nordhaus's estimates of the area of land lost upwards by a factor of ten and increase the value of land lost in less developed countries, such as Bangladesh. They also add an amount to cover the cost of resettling refugees forced to move as a result of sea-level rise. Even without attempting to include nonmarket effects, these revisions result in benefits of reducing global warming ten times greater than the medium damage scenario estimates given by Nordhaus.

An obvious next step would be to include the economic value of nonmarket benefits related to actions that reduce global warming. While much work in environmental economics during the last 20 years has focused on such nonmarket valuation, the application of benefit measurement techniques to the greenhouse effect confronts two key problems. First, many individuals may be unsure as to the meaning of the greenhouse effect and its related damages and the implications to them of preventing an increase in emission of greenhouse gases. While the valuation of benefits under uncertainty has been the subject of much attention in the environmental economics literature (e.g., Meier and Randall 1991), others have expressed concerns that poorly informed consumers cannot be relied upon to make sensible decisions about complex environmental phenomena (e.g., Sagoff 1988). Second, individuals may be unwilling to trade off increases/decreases in global warming against losses/gains in income. If a certain proportion of the population hold rights-based beliefs, this would prevent them from agreeing to such trade-offs. For example, environmental campaigners might believe that future generations have the right to live in their own homeland regardless of the utility this gives or of the costs to society. Such noncompensatory decision rules are referred to by neoclassical economists as representing "lexicographic preferences." These two issues are now considered in more detail.

## 4.2. UNCERTAIN FUTURES

Introducing uncertainty has lead some economists to argue that reducing greenhouse gas emissions is desirable even if the expected costs of doing so are known to exceed the expected benefits (e.g., Cline 1992, Spash and Hanley 1994a). The reasoning is based upon society being risk averse. Thus, the costs of reducing greenhouse gas emissions by 75 percent might be known to be \$1 trillion. The benefits of reducing greenhouse gas emissions might range from \$0.25 trillion to \$10 trillion, with an expected value of \$0.8 trillion. If society is risk averse, it can prefer to incur the certain loss of \$1 trillion (the "certainty equivalent") rather than the expected loss of \$0.8 trillion with the potential for higher losses. Thus, greenhouse gas control could be regarded as an insurance premium against known but uncertain future states of the world, where the probability of those states occurring is known or knowable. This would be consistent with an expected utility framework and could justify a safe minimum standard approach. Once a threshold with a safe margin has been chosen, the economy could be "safely" allowed to emit greenhouse gases.

However, in a fragmented world, risk aversion leads to a risk externality; that is, the risk is placed upon "other" societies (e.g., future generations), rather than leading to greenhouse gas control. Thus, (world?) government intervention would then be required to correct both a pollution and a risk externality. More seriously, this economic approach to an uncertain world requires that potential future states be reduced to probabilistic events. As a result, Spash and Clayton (in press) note, several questionable, implicit assumptions are being made by the analyst:

1. A cause-and-effect relationship can be established to determine the outcomes to be included in the set of possible future states; this is a difficult task for global warming.
2. Probabilities can be associated with all future states of the world. The problem is that an action leading to an event may be recognized as a possible state but without a probability being attached to the outcome. Thus, an event can be expressed as uncertain yet have no associated probability of occurrence. The probability itself may be unknown or nonexistent. (Such a division of risk and uncertainty can be found in Keynes [(1921) 1973].)
3. The type of missing knowledge being analyzed concerns the risk associated with the occurrence of outcomes. However, all the models of the behavior of complex systems, such as environmental and economic systems or their interactions, are imprecise and limited in their scope. These limitations arise for a number of reasons: ignorance about a particular system, ignorance about the behavior of a class of systems, and the indeterminate nature of some complex systems (which can become chaotic at various points). This means the behavior of such systems can only be modeled in probabilistic terms, for limited domains, or for a limited time.
4. The distribution of risk over space and time is unimportant when judging appropriate action. Yet many decisions involve choosing among options that have different risks for different people at different times. Part of the issue here concerns the perception of risk. The general public has been observed to reject very low-probability, high-loss risks which experts judge to be acceptable (Freeman 1993). Thus, the experts could vastly underestimate the potential welfare costs that these risks impose upon people.

In addition to these problems, there are areas of ignorance related to sources of utility. First, some elements, substances, and organisms on the planet have yet to be utilized directly by humans. This can be viewed as uncertainty and ignorance over future use patterns. For example, losses in biodiversity due to global warming can cause future losses of which present humans are ignorant. Second, many of the features of nature that are directly utilized in economic processes are dependent on features of nature that are indirectly utilized. Current biomass depends on an ecological infrastructure that enables flows into human systems but is ignored itself. Thus, stratospheric ozone can be depleted by CFCs, allowing higher levels of UV-B radiation to reach the surface of the planet; this would in turn affect the marine biota at the base of the food chain on which harvested species of fish depend. In this way, uncertainty and ignorance pertain to ecosystems functions in addition to risk.

Once the above arguments are accepted, an optimal level of the insurance premium would be undefinable. Thus, while greenhouse gas control can be viewed as an insurance premium, this definition tends to reject the wider concepts of uncertainty and of ignorance. Society needs to accept that some areas of ignorance cannot be easily placed into the framework of knowledge about systems (Faber et al. 1992). In general, where altering the potentialities of systems causes changes that are, in principle, unpredictable, the appropriate response is to maintain options. This implies accepting the importance of different views on the same problem, questioning current knowledge, and emphasizing criteria of flexibility and reversibility (Spash and Clayton in press).

## 4.3. NONCOMPENSATORY CHOICES

The typical approach to the valuation of nonmarket environmental assets (such as wildlife) in environmental economics has been to treat such assets identically to marketed goods and services (e.g., Braden and Kolstad 1991). A standard theoretical assumption is the existence of the direct utility function which includes all items of value. The willingness-to-pay (WTP) of an individual to prevent a loss of an item relates to the impact on its utility function. An individual would therefore be prepared to give up some consumption of other goods to maintain a constant utility level if reducing greenhouse gases made him/her better off. The WTP amounts are typically summed across all affected individuals to obtain an aggregate WTP figure. Similarly, the minimum compensation demanded to accept an increase in greenhouse gases can be calculated (WTAC). In this case, expenditure on other goods needs to rise to compensate for the damages caused by global warming, keeping the agent at their initial level of welfare. The welfare measures of WTP and WTAC are expected to diverge, due to the potential for loss aversion (Knetsch 1990), income effects (Willig 1976), and substitution effects (Adamowicz et al. 1993).

However, besides the information problems outlined above, some individuals may treat certain environmental goods differently from the manner suggested by this theoretical framework. If an individual believes that aspects of the environment, such as wildlife, have an absolute right to be protected, then that individual will refuse all money trade-offs that decrease what is regarded as an environmental commodity in the neoclassical framework (Spash and Hanley 1994b). Thus, WTAC would be infinite, since the respondent believes that greenhouse gas damages should remain at or below their current level (i.e., no increases in greenhouse gases should be allowed). Simultaneously, WTP to reduce greenhouse gases can be positive or zero depending upon the income constraint. In fact, individuals may express a zero WTP as a protest against the implication that such things as the rights of future generations could be traded for other goods or money.

Such a noncompensatory stance can be viewed as evidence of a lexicographic preference. Lexicographic preferences mean that utility functions including greenhouse gas reductions are undefinable for an individual (since the axiom of continuity is violated) and that indifference surfaces are single points (Gravelle and Rees 1992). The implication is that one good is immeasurably more important than another, which leads to lexicographic preferences being regarded as unrealistic and unlikely to occur in economics (Malinvaud 1972). However, some evidence for the existence of lexicographic preferences has been put forward (Stevens et al. 1991, Spash and Hanley 1994b).

A belief system that denies trade-offs drives at the heart of modern welfare economics, which has been built around the Kaldor-Hicks potential compensation test. This test allows for projects to be approved where there is the potential to make at least one person better off and none worse off—i.e., some potential resource distribution after the project could achieve a Pareto improvement. Thus, knowledge of the required potential compensation is necessary and, in the neoclassical framework, would be based upon individual preferences. This criterion becomes inoperable once compensatory amounts become infinite. Furthermore, cost-benefit analysis itself is meaningless under noncompensatory preferences. The extent to which this issue is relevant to greenhouse gas control depends, at least partially, upon how far future generations can be compensated for damages they suffer as a result.

## 4.4. RESPONSIBILITIES TO FUTURE GENERATIONS

Spash (1994) has argued that the greenhouse effect could have serious impacts upon future generations while actually benefiting their predecessors. The standard application of cost-benefit analysis to the greenhouse effect, even if all costs and benefits could be calculated from individual preferences, would give the impression that the future is almost valueless, largely due to discounting. As Nordhaus (1991a: 936) has stated:

> The efficient degree of control of greenhouse gases would be essentially zero in the case of high costs, low damages, and high discount-

> ing; by contrast, in the case of no discounting and high damages, the efficient degree of control is close to one third of greenhouse gas emissions.

The distribution of net costs in the future, and net benefits now, makes the emission of greenhouse gases appear falsely attractive. Spash (1993) has criticized four common reasons for giving less weight to the expected future damages of long-term environmental pollution than if they were to occur now. These concern who constitutes the electorate, uncertainty over future preferences, the extinction of the human race, and uncertainty over future events. Without these justifications, discounting loses its moral imperative. Cost-benefit analysis as commonly applied would use an arbitrary but positive social discount rate. Thus, implicitly, some concern for the future effects of global warming would be shown, but the extent of this concern would depend upon the discount rate chosen. The problem that faces economists, in falling back on the use of a positive rate, is that their policy conclusions still have serious long-term implications which raise the need for a moral justification for the procedure.

However, there is a persistent view that the current generation should be unconcerned over the loss or injury caused to future generations because they will benefit from advances in technology, investments in both human-made and natural capital, and direct bequests. Adams (1989) has raised this exact issue in terms of alleviating our responsibilities for global warming. While fossil fuel combustion implies foregone opportunities for future generations, they "typically benefit (in the form of higher material standards of living) from current investments in technology, capital stocks, and other infrastructure." However, this line of reasoning confuses actions taken for two separate reasons. That future generations may be better off has nothing to do with societies consciously deciding to compensate the future.

If society has in fact been undertaking investments with the express purpose of compensating future generations for global warming, the lack of publicity has been conspicuous. More importantly, this would imply that the extent to which the future will be better off has in some sense been balanced against all the long-term environmental problems. That is, society cannot take global warming and see the future as better off, and then ignore global warming and take ozone depletion as compensated, and then ignore ozone and balance nuclear waste against supposed future well-being. Each case of long-term damage implies compensation which is distinct from catering to the general needs of future individuals.

This distinct nature of such compensatory transfers has been neglected (Spash and d'Arge 1989; Spash 1993, 1994). The greenhouse effect as characterized earlier creates an asymmetric distribution of losses and gains over time. Intergenerational compensation would counterbalance the negative outcomes of global warming by positive transfers, while not interfering with basic transfers. For example, assuming egalitarianism, the maintenance of the same welfare level fails to compensate for global warming. Yet the suggestion has been made that spreading the costs of global warming equitably across generations is an acceptable solution (Crosson 1989).

The problem with the latter approach arises from the economic view that changes in units of welfare are equivalent regardless of their direction. The standard approach of economists can be traced at least as far back as Bentham ([1843] 1954: 438):

> ...To the individual in question, an evil is reparable, and exactly repaired, when after having sustained the evil and received the compensation, it would be a matter of indifference whether to receive the like evil, coupled with the like compensation, or not.

Unfortunately, this approach treats harm as reversible by good. In general, doing harm is not canceled out by doing good. If an individual pays to have a road straightened and saves two lives a year, that person cannot shoot one motorist a year and simply calculate an improvement (Barry 1983). This argument is most apparent where the right to life is involved, but it can be extended to other areas where rights are accepted to exist. For example, assume individuals of a nation are accepted to have a right to live in their own homeland. Sea level rise due to global warming floods the Maldives and violates this right. Of course the Maldavians can be relocated and compensated, but this approach is unacceptable given the previously stated right.

The objection free-market economists might raise to the imposition of such rights is that freely contracting parties are prevented from entering into agreements of their own free will. As Bentham went on to point out:

> What is manifest is—that to no person, other than the individual himself, can it be known whether, in this instance, between an evil sustained, and a benefit received on account of it, any compensation have place or not.

That is, the individual is her or his own best judge of welfare changes. If the Maldavians believe they are better off in their new homeland, then who is to deny the acceptability of this exchange? The difficulty in the intergenerational context is that the individuals who will be impacted are unavailable for comment. In order to protect these individuals from unjustified harm, rights could be used, so that what appeared to be a problem for the use of rights can be viewed as an argument in their favor. In fact, this approach would define harm as a violation of the rights adopted by society.

The appeal to the "safe minimum standard" can be viewed as an example of constraining economic trade-offs by introducing rights. This standard advocates the protection of species, habitats, and ecosystems unless the costs of doing so are unacceptably large. In the case of global warming, Batie and Shugart (1989) argue that the safe minimum standard would support emission reductions despite apparently high costs. However, the withdrawal of the right of, say, a species to exist at some cost implies a basis of the right within utilitarian morality. This view contrasts with rights in the context of a deontological philosophy.

More generally, the economic process of exchange can be viewed as the transfer of goods and services within a framework of established rights. In this case, rights are only valid in as far as the institutional setting allows them to exist. Yet the question being probed here is one of the existence of a right of future generations in the sense of a natural right, not merely the recognition by a piece of legislation in a particular society at a particular time that such a right is valid. A natural right can be defined as a right based on intrinsic value (Nash 1989). The United Nations charter of human rights represents an internationally accepted set of goals to which the world aspires. The fact that these rights are violated does not reduce their importance. Yet within these rules, there is little comfort for future generations. A generous reading would only protect the future indirectly under articles intended to protect the current generation. Public concern is starting to be expressed regarding this oversight, and this has reached the extent of a global petition to the United Nations (Cousteau Society 1991).

If rights that protect future individuals from the results of our greenhouse gas emissions are accepted to exist, the scope for trade-offs commonly assumed in economics will be drastically reduced. Compensation payments are no longer licenses for society to pollute, provided the damages created are less than the amount of compensation—in which case, compensation cannot be used to excuse the continuation of greenhouse gas emissions. Irreversible damages that will occur regardless of greenhouse gas emissions reductions would require compensation. In order to protect the future from potential infringements upon this right, actions with uncertain intertemporal consequences would have to be avoided and environmentally benign production and consumption processes encouraged.

Due to the cost of enforcing the rights of future generations to remain unharmed, the current generation has a vested interest in denying those rights. Continuing to emit greenhouse gases at current rates denies the future the right to remain undamaged and asserts the dominance of the current generation. The current generation is then being asked to change the present rights structure, as found within society, in a manner detrimental to its own interest. The dictatorship of the current generation allows the imposition of damages regardless of the gain now and the extent of future damages.

### 4.5. FUTURE PROSPECTS

Cost-benefit analysis runs into problems due to uncertainty in the estimation of benefits, attitudes toward future generations and, more fundamentally, the very size of the problem (there is a point at which marginal welfare analysis loses its theoretical basis). These problems prevent a clear answer as to what should be done, and economics cannot, of course, provide a complete answer. The costs of reducing carbon dioxide emissions may be quite high, but because the benefits of reducing emissions are beyond economists' ability to estimate, the extent to which control options should be adopted, on efficiency grounds alone, is unknown. Thus, a practical way forward is to adopt "no regret" or "double dividend" policies. These are actions that can be justified on their own account but that also reduce global warming. Such policies include solving Third World food insecurity, increasing energy efficiency, cutting CFC emissions, preventing deforestation, and encouraging reforestation. Similarly, if energy prices are below their marginal social cost (excluding global warming impacts), then raising energy prices will make utilization more efficient and reduce greenhouse gas emissions.

The economists' appeal to cost-benefit analysis attempts to take losses and gains of controlling harmful activities directly into account. In doing so, the rights of future generations are violated when the costs of controlling the greenhouse effect are deemed to exceed the benefits of that control. The use of cost-benefit analysis therefore denies the existence of inalienable rights because harm and good are seen as equivalent. However, harm is recognizably different from good, and the deliberate infliction of harm is morally objectionable, as recognized in modern democracies. If remaining unharmed is defined as a set of rights given to future individuals, actual compensation is required if these rights are violated. If at all possible, these rights should not be violated and people should be freed from actions that deliberately externalize the risk of damages by imposing it upon others. These issues begin to reflect upon the role of cost-benefit analysis and some of the problems apparent with WTA measures where a structure of rights enforces a compensation principle.

The task of defining harms will be difficult, but as suggested earlier, the United Nations charter of human rights provides guidance. A further difficulty arises in being uncertain as to when an action might result in the violation of such rights. In terms of the greenhouse effect, there is a strong case to believe that numerous contraventions of these basic rights will occur. The point here is to emphasise a fundamental basis for human action in morality.

## 5. A Third World Perspective

If there is one thing the Earth Summit brought home to the Third World, it was the Machiavellian primacy of politics over ethics. For in the final analysis, it seemed that the more powerful interests of the industrialized nations prevailed and that recommendations were based more on politics than on considerations of justice and ethics (see, e.g., Johnson 1993). Building upon previous sections of this chapter, we herein more particularly focus on the following implications of climate change from the perspective of developing nations: (1)the burden of risk and the price of change, (2)equity-based ecological development, (3)intergenerational responsibility, (4)environmental and financial debt, and (5)environmental rights and ecological duties.

One response to the possibility of global climate change would be to do nothing but to collect data and analyse it in the hope that we can further reduce our scientific uncertainty and only act when we have sufficient certainty with regard to the effects our interventions may have. Obviously such an option supports the present status quo and those privileged by it. A second response would be to implement a global effort to reduce greenhouse gas emissions, since we know that these have the capacity to affect global climate, and the probabilities are that the resulting changes will disproportionately affect the poorer and more vulnerable countries adversely. Clearly such a response favors those people who are least able to cope with the consequences of climate change.

Obviously, different responses to global climate change will affect groups of people differently. The essential question with regard to risk management in this situation is whether and to what extent risks and costs of climate change and mitigation policies should be borne by those most vulnerable and least able to afford them or whether they should be borne by people in affluent nations who are more able to afford the costs and who also are benefiting by the present status quo. Will it be the political rather than the ethical implications of the question that will decide our response?

We herein opt for an ethical perspective consequent on the earlier part of this paper. The issues we raise in this section are of course not exclusive to climate change. Rather, this is an area that helps to illustrate well the global dimensions of the world's ecological crisis. In other words, when we have a global crisis, only a global response can meet it, and for this we need to act as a global community. Ecological thinking forces us to this conclusion.

Moreover, our vantage point is that of the southern or developing nations. Nevertheless, we are aware that there are conditions of poverty in more developed nations as well as pockets of affluence in developing nations. The homeless shivering in the cold whom one sees in New York and the mansions gleaming in the sun in Delhi are surely telling images of this anomaly. Our discussion could be further refined to take cognizance of such situations. However, at the risk of over-generalization, we are confining ourselves here to the broader aspects of climate change issues between developed and developing nations.

## 5.1. THE BURDEN OF RISK AND THE PRICE OF CHANGE

Who should bear the burden of risk and who should pay the price of climate change? If we wait for more scientific data before adopting effective measures to mitigate climate change, then we are not reducing the risk of climate change and its consequences, but rather we are increasing it. The longer we delay implementation of effective mitigation policies, the more difficult it will be to reduce risk or ameliorate adverse consequences of climate change at some future date. If we want effectively to reduce the risk of climate change, then we must limit the emissions of greenhouse gases sooner as opposed to later.

The very complexities and uncertainties make a cost-benefit analysis of the risks involved inadequate and unfeasible. The use of cost-benefit analysis is tantamount to basing decisions (in large part) on economic calculations and political priorities (Ghosh and Jaitly 1993). The political resolution to risk, change, and the sharing of economic costs typically is dependent on the bargaining power of the parties involved and usually ends up with the weakest bearing the burden of risk and the poorest paying the price of change.

On the other hand, an ethical resolution of the question of who should bear the burden of risk and who should pay the price of climate change would be value-based and rather different. An ethical management of risk would require first that risk be minimized and then redistributed equitably, if indeed we are to face risk as a community and not as isolated individuals—for a community can hardly be considered ethical if it protects the powerful to the neglect of the powerless. In reality, the most effective indicator of equity in a community is not how the strongest fare but rather how the weakest are able to cope.

Furthermore, risk reduction and its equitable distribution in the context of the global climate system will obviously demand change, both in human consumption patterns and in production technology. With regard to the first, for the poor this will mean an increase in consumption to meet their basic needs and to improve their quality of life to acceptable levels. Allowing these basic needs to remain at the subsistence level not only is ethically unjustifiable but also is ecologically unsound. We shall return to this point later.

For the rich, changes in their consumption patterns will mean a reduction or at least a restriction of affluent wants. This can actually lead to, or at least it has the potential for, an enhancement of wealthy persons' quality of life, even at the cost of a reduction in their standard of living. As Birch (1976) notes: "The rich must live more simply so that the poor can simply live." Indeed, this is a crucial issue in the whole sustainability debate, but a thorough examination of it would take us beyond the scope of this paper, though it does need to be developed elsewhere to deepen this discussion.

With regard to the second factor, changes in production technologies for the poor, who are surviving at subsistence levels, this must mean an increase in productivity. One can hardly in good conscience urge the people of developing nations to forego development programs that represent their only chance to escape from the poverty to which they are subject. But if this is to be done in an environmentally friendly manner without externalizing the costs, as happened with the first industrial revolution that was the basis of the present development and affluence of the First World, then there must be a change toward more environmentally friendly technologies. Unfortunately, at present the developing nations do not seem to have the resources to buy such technologies from the more developed nations, or the research and development capabilities to implement them on their own. For the rich, changes in production technology are concerned more with decreasing waste while at the same time expanding employment and other benefits. While these forms of new technologies are being developed, their transfer to poorer nations still remains a much-disputed and problematic area.

Globally speaking, achieving sustainable development will very much depend upon how such problems are resolved. A power-based political approach will only postpone and accentuate the already significant risks of global climate change. In our opinion, what is required really is a structural adjustment on a global scale, not only of the economic structures of our societies, which might affect the developing nations more, but more particularly in our lifestyles as well, and this concerns the more developed nations most urgently.

In other words, we need to change the manner and the kind of the goods and services that are provided with regard both to the way they are produced and the way they are consumed. We must realize that ecological productivity differs from productivity in the economic sense, because the economic utilization of resources through extraction under certain conditions undermines and destroys vital ecological processes, leading to heavy but hidden diseconomies (Goodland et al. 1993). Further, the nature of these diseconomies can be understood only through the understanding of ecological processes operating under conditions relatively undisturbed by humans (Angermeier and Karr 1994).

We realize that we cannot cope with the problem of distributing the risks and cost of climate change except as a global community bound together by a common destiny. A failure of the world community to take decisive action now to mitigate the risks of climate change will require even more urgent and drastic action later, if indeed it is not too late by then. Is it not curious, though, that some would want scientific certainty to be established before taking actions to mitigate global climate change, while at the same time certainty is never demanded of economic policy interventions, even though these are based on statistical probabilities? But then too often such interventions are dictated by the market rather than ethically derived from commitments to members of the global community.

## 5.2. EQUITY-BASED ECOLOGICAL DEVELOPMENT

Agenda 21 recommendations reflect the widely held view that equity is integral to achieving sustainability. Indeed, if it is not the sufficient condition, it certainly is a necessary one, the sine qua non for sustainable development. Granted that certain kinds of development can be unecological, we still have to face the fact that in the struggle for survival within a resource-poor or limited environment, poverty and pollution are inexorably linked. If the poor have no sense of opportunity in the future, then one can hardly expect that they will sustain and renew their environment in the present. When involuntary poverty becomes the poor's *fait accompli,* then by necessity they struggle simply for day-to-day survival, a struggle in which they many times do not succeed. All too often they are caught in a downward spiral of marginalized people trapped into marginalized areas.

Given the present technological and other capabilities that exist on a worldwide basis, it should be possible to alleviate conditions of poverty significantly for many people, if only the necessary political will for the task could be mustered. Further, it is ethically unacceptable that concerns for humans be displaced by an inequitable distribution of the goods of this world. Indeed, inequality only sharpens the sense of relative deprivation that the poor feel when they find themselves in want in the midst of the plenty of the affluent. Thus, if sustainability were imposed on the developing nations at the cost of their development, then this means that those nations would remain impoverished in order to sustain the more affluent nations. This situation, were it to occur, would be based more on political and economic power than on an ethical response to the problem. Sustainable development must as a minimum meet the economic challenges of providing for basic needs for all people.

It is also ethically unacceptable that our concern for nature be allowed to negate fundamental human rights. Indeed, a true concern for nature cannot set humans and nature in opposition. Rather, humans must be perceived as a part of nature that preserves, protects, and restores ecological integrity. In fact, only when human and nonhuman nature are in harmony can both be protected. Ecologically based thinking necessarily leads to an awareness of interdependent communities, as Gandhi envisaged, in ever increasing and inclusive circles, to include the human, the biotic, and the cosmic as well, and even the transcendent (Ramamurthy 1986). Of course, there is a danger that humans will become too anthropocentric in their thinking (see, e.g., Devall and Sessions 1985). Yet, ways must be found to accommodate the needs of both human and nonhuman nature.

Global climate change is a problem that transcends national boundaries. Even if it were possible to achieve sustainable development in one nation at the cost of unsustainability in another, as happens all too often in exchange relations between developed and developing nations, this would do little to mitigate the problem of global climate change, because it is a transboundary problem. Unfortunately, national sovereignty is often used to thwart remedial action, infringe upon environmental rights, and negate ecological concerns (Johnson 1993). Using national sovereignty to obfuscate ecological concerns or human rights is not, of course, the prerogative of any single nation, whether developed or developing. But when the more powerful nations, who are the least in danger of having their sovereignty threatened, indulge in such obscurantism, it is all the more galling. Thus, when then President Bush of the United States said at the Earth Summit Conference that nothing would make him compromise his nation's way of life, when that lifestyle threatens the global environment, such a statement may be good domestic politics, but it is from an international perspective grossly unethical. Certainly, such positions cannot be the starting point for any international measures to mitigate the problem of global climatic change.

Equity demands a reduction of the gap between the rich and the poor both intranationally and internationally. If this reduction is to be done within the carrying capacity of the earth, then further problems arise. If the poor of the developing nations aspire to reach the same consumption levels of the developed nations, then this cannot be accomplished within the earth's potential carrying capacity as we know it, in spite of any technological advances or institutional changes we may realistically hope for. To be sure, it seems improbable to narrow this gap solely by reducing the consumption of the rich, though this would surely be fairer than restraining the development of the poor. Is it realistic to expect a person to be elected to political office in a developed nation on the promise of reducing consumption? And yet the imperative to live within ecological limits and the ethical mandate for equity seem to demand that leaders of developed nations promulgate programs to reduce consumption of natural resources and the generation of harmful chemicals such as greenhouse gases.

Accordingly, some kind of redistribution seems to be warranted. A more equitable distribution of consumption and production between developed and developing nations, in a manner that will allow both to become sustainable, seems to be necessary. But just as sustainable development must meet the ecological necessity of containing itself within the carrying capacity of the earth, it also must meet the ethical imperative of equity among nations. Some kind of planetary bargain between the rich and poor nations for a more stable and sustainable world would seem to be called for rather than waiting for poverty and environmental degradation in less developed nations to pose a threat to the more developed nations before appropriate action is taken.

A beginning for such a bargain with regard to greenhouse gas emissions would be to consider quotas based on a per capita basis and not on an aggregated national one. This would be an equitable way of fixing the responsibility for change on the polluters, who must pay the price for it. National emission quotas would then be fixed not in terms of present levels of pollution but in terms of population size (which needs to be limited) on a per capita calculation, not an aggregated nationwide one (Agarwal and Narain 1991). Those countries not using their quotas could then trade them in with those unable or unwilling to limit themselves to theirs. While greenhouse gas emission must be reduced in the long term, in the short term such trade-offs could be used for a transfer of technology and resources that would lead to a more equitable development now and a more sustainable one later. Moreover, such transactions would be a matter of trade and not aid. This would make for less unequal exchange between industrialized and nonindustrialized countries. Indeed, until such unequal and unfair exchange between rich and poor peoples, nations, and regions, both intranationally and internationally, is remedied, there seems little possibility of sustainable, let alone regenerative, development on the global scale we so urgently need.

On the other hand, the suggestion of tradeable carbon permits is highly controversial. The permits raise the question of how far responsibility for pollution is to be allowed if a nation (or corporation) can purchase the right to pollute versus the point of view that responsibility for limiting pollution should be based upon moral as opposed to economic or political grounds or bargaining ability.

### 5.3. INTERGENERATIONAL RESPONSIBILITY

Although philosophers are divided on the exact nature of responsibilities to future generations, the view that present generations have responsibility or obligation to future generations is gaining more widespread acceptance and is, of course, reflected in many recommendations contained in Agenda 21. In the final analysis, such a responsibility must be based on a sense of bonding across generations (Care 1982). If we feel this bonding with the future, should we not feel the same with past generations as well? If we are responsible to the future, are we not also responsible for the past? Responsible not in terms of feeling guilty for what our ancestors may have done, but rather in the sense of feeling responsible to address the adverse consequences of their actions that still affect us, especially if we have been advantaged by their actions. In other words, can we accept the benefits left to us and not make remuneration for the harm they might have done to others?

An ecological principle now gaining acceptance is that "the polluter pays." If the polluter pays for the pollution caused in the present, who should pay for the pollution caused in the past and that still affects us now? While present people may not be guilty of causing past pollution, should they accept the advantages obtained from such past actions without making remuneration for them? Would not this be like someone keeping stolen property even though that person actually may not have been guilty of the theft? And if, as we know, some people's ancestors because of their unecological development have in the past borrowed from our common future, should their descendants now refuse to remunerate in the present those who are being affected adversely by this? Consequently, if present members of industrialized nations enjoy and accept a certain amount of affluence because of past development that has led to high levels of greenhouse gases in the atmosphere, thereby threatening other people spatially and temporally, should they not also be responsible for mitigating the harm caused by such development and affluence that they have accepted?

In a sense, the past still exists in the present, for no present can escape its historical context. Indeed, there can be no intergenerational responsibility without such a context. The irony, of course, is that those nations and peoples whose prodigality in the past has degraded the global environment now are urging restraint on those who have been frugal, out of necessity perhaps, but who now aspire to a higher standard of living. In fact, the powerful governments and multinational corporations of developed nations responsible for significant global environmental degradation are using the economic levers of aid, trade, and debt to enforce environmental discipline in the developing nations that have little political clout to use against them (Agarwal and Narain 1992). Such a situation could easily degenerate into a new sort of imperialism or colonialism, as the Indian finance minister has cautioned (Singh 1993).

Consequently, a certain alarm has been expressed at the rapid industrialization of some developing countries in Asia. If every Chinese person or household has a refrigerator, what will happen to the ozone layer, especially if the Chinese continue to use older refrigeration technology? But when there were two cars in many Americans' garages— both adding carbon to the greenhouse effect—few if any governmental leaders acknowledged the role of American technology and consumption in contributing to global problems such as climate change, much less took steps to mitigate the problem. Obviously, concern for unecological development in Asia only can become legitimate by an equal concern for the unecological effects of development in other countries, not excluding their prodigal past.

It would seem that a community cannot be built unless and until people come to terms with their past. Unless past actions are redeemed, at least in the sense of remunerating those who have suffered or will suffer because of advantages accrued to present people due to unecological past actions, it is unlikely that a sustainable future will be created. Only when a global community transcends both space and time will a prospect exist that the global ecological crisis will be dealt with effectively.

## 5.4. ENVIRONMENTAL AND FINANCIAL DEBT

Chapters 33 and 34 of Agenda 21 deal respectively with financial resources and mechanisms to promote sustainable development and environmental protection and with issues relating to the transfer of environmentally sound technology. The transfer of more appropriate technology to mitigate global climate change is, of course, dependent upon the developing nations' acquisition of necessary financial resources. Chapter 33 identifies multilateral development banks and funds, specialized agencies and other United Nations agencies and international organizations, multilateral institutions for capacity-building and technical cooperation, bilateral assistance programs, private funding, investment, innovative financing, and debt relief as the primary sources and means of financial support for implementation of Agenda 21 recommendations. Interestingly, during the Agenda 21 deliberations, the head of the World Bank stated that the bulk of developing countries' investment needs for environmental purposes must come from savings that they achieve through improved economic policies, from private sector sources, and from improved trade, although some recognition was given to the need for increased aid from developed to developing nations (Johnson 1993).

Many developing countries have significant financial debts to other governments or world lending institutions, and many are selling off natural resources with little environmental regulation in order to raise income to finance their debt burden (Goodland et al. 1993). Financial borrowing mortgages the future of the next generation of a group by making them debtors to the creditors of this one. National financial debts are not written off if a government fails or a generation passes. The debtor pays, or the debtor's children, for such financial debts are inherited. The debt burden is forced onto the next generation by international financial agencies. The agencies often justify this by the need to support the international global economic order, which they claim would collapse without such accountability. International financial bodies may reschedule payments or make structural adjustments, but there is no reprieve from such debt—there is no free lunch.

Financial borrowing, then, is living beyond one's financial means, but there is an ecological parallel. There is an ecological borrowing, which involves living beyond the limits of one's ecological resources—that is, utilizing natural resources at a rate that exceeds their rate of regeneration, externalizing costs, polluting the global commons, and incurring a debt with nature that future generations will have to pay for. This situation is tantamount to a Faustian bargain between humanity and nature that leaves little possibility of appealing for debt relief, rescheduling, or default (Korten 1992).

If a financial debt is to be taken seriously, as it is by lending governments and international agencies (in other words, the debtor must pay), then why should environmental debts not be taken just as seriously (in other words, the polluter must pay)? If there is no such thing as an economically free lunch for anyone, why is it that there seems to be an ecologically free dinner for some? Why should not structural adjustments be made for past polluters to help them undo the damage done by the pollution they have caused and thus repay the environmental debt that they owe to the global community, especially the poor, who suffer most from such environmental degradation? Repayment of environmental debts by the rich are unlikely to the extent that decisions are based on political and economic power as opposed to ethical reasoning, because the poor of this world have little bargaining power in the international political arena and economic markets.

One way of paying an environmental debt would be the transfer of technology and resources to the less developed countries from the more developed ones responsible for past pollution. This could be a feasible way of reversing the transfer of assets from the less developed to the industrialized countries, as is happening at present and which perpetuates the debt crisis. This could also help the less developed countries to bypass the polluting first stage in the industrialization process, which the present industrialized countries went through, to environmentally cleaner and ecologically more friendly technologies. Such a transfer of technology then is not a matter of aid with all of its political implications but rather a matter of right, of ethical demands, and of ecological urgency. To this extent, the resource transfers could be interpreted as polluters' dues made toward repayment of environmental debts. International agencies could cost the environmental debts of the industrialized countries and suggest how they could be written off against the financial debts of the less developed countries. International agencies have been established to deal with the financial debts of less developed countries. If the global community takes the ecological crisis seriously, then international bodies should be established to deal with the environmental debts of developed nations as well. The creation of such international bodies also would seem to parallel the globalization of the world's economy. If there is to be a single global financial community with greater interdependence, this must in turn call for a single global ecological community with correspondingly greater reciprocity as well.

## 5.5. ENVIRONMENTAL RIGHTS AND ECOLOGICAL DUTIES

We suggest that the issues raised in this chapter call for the development of a new social contract, not just to enforce legal conventions between nations but also to foster a global community for the global environmental crisis and guarantee further environmental rights for individual persons and local communities. In other words, action is needed not only at the international and national levels but also at the local community level. For the only sound way of building an effective global community is with a bottom-up process, although this may need some top-down facilitation. Of course, this suggestion is hardly new (Uphoff 1982).

Indeed, Gandhi's decentralized logic of a "consociational" democracy of interdependent but self-reliant local communities makes more sound ecological sense than the highly centralized model so prevalent in modern nations. Accordingly, nations should derive some of their authority from local communities, while some of their sovereignty should be yielded to the global community, because the nation-state is too large for effective local community management and too small for effective global management (Agarwal and Narain 1992).

Environmental rights must include not just the right to a clean and productive environment, which is the concern of the rich, but more importantly the right of survival and subsistence with dignity for all persons and communities, which is the preoccupation of the poor (Guha 1988). Further, ecological duties and citizenship responsibilities also must include community obligations at the local, national, and global levels. Legal conventions among nations not founded on human rights and civic duties at more local levels only legalize injustice and institutionalize ecological degradation, which already is creating environmental refugees and may spawn ecological terrorists out of desperation. So also does administrative control that is insensitive to the needs of the underprivileged and the powerless in a country. Indeed, the question of legal liability and/or administrative regulation with regard to environmental issues remains very problematic, especially at the global level (Ghosh and Jaitly 1993).

## 5.6. PRESENT PERCEPTIONS AND FUTURE PROMISE

The ecological crisis, as exemplified in global climate change, forces us to quest for a community that is equitable, sustainable, and participative, even as it stretches across geographical space and different generations, and increasingly interdependent at the local, national, and global levels. This quest becomes more crucial in our anomic and alienating society that is so unequally divided between the affluent and the impoverished. In fact, it is community that is the answer to both the alienation of poverty and the anomie of affluence (Moltmann 1989). Further, this extensive community also must have its intensive dimensions, embracing the human, the biotic, and the cosmic and even opening to the transcendent. Toward this end, humans must be perceptive to the development of new and appropriate ethical norms and worldviews to serve as guides to mitigate problems such as global climate change. How the world responds to the problem of global climate change inevitably will define our future in irrevocable ways. Indeed, the present is but a parable of promise and anticipation for the future.

## 6. Conclusion

Agenda 21 recommendations to protect the earth's atmosphere focus, in part, on: (1)strengthening the scientific basis for sustainable management, (2)enhancing scientific understanding, (3)improving long-term scientific assessment, and (4)building up scientific capacity and capability. Importantly, Agenda 21 recommends adoption of a precautionary approach to protect the atmosphere by stating that in the face of threats of irreversible environmental damage, lack of full scientific understanding should not be an excuse for postponing actions that are justified in their own right. It states further that the precautionary approach could provide a basis for policies relating to complex systems that are not yet understood fully and whose consequences of disturbances cannot yet be predicted.

These types of recommendations reflect the scientific uncertainties surrounding the causes of climate change, the rate and magnitude of change, and the consequences of this change to ecosystems and human health. Of course, a recommendation to adopt a precautionary approach creates a public policy dilemma. Scientists are unable to make reasonably accurate predictions of future climate, yet without such predictions, the consequences of climate change and the societal responses and alternative choices of action cannot be assessed fully. Yet it is known that there is a substantial risk of climate change and that the consequences will affect countries and regions differently, as well as future generations. Thus, from the scientific understanding of the problem of climate change, including the problem of uncertainty, flows the ethical problems of: (1)whether to take action to mitigate the problem despite the uncertainties, or whether to delay action until more information is obtained; and (2)how to distribute risks and burdens both spatially and temporally. In addition, while Agenda 21 recommends the use of cost-benefit analysis and other forms of economic valuation and methods to assess the consequences of climate change, it must be recognized that such analyses and methods are value-laden and do not take into account sufficiently how costs and benefits are distributed, including across generations. Further, they do not take into account the protection of nonhuman nature adequately. Thus, their application should be viewed as an ethical problem requiring analysis and resolution lest decisions be based on economics alone and not on ethical reasoning.

The adoption of a precautionary approach as suggested by Agenda 21 would seem to be most consistent with reducing human health and environmental risks, would be based upon ethical reasoning as opposed to economic considerations and political power among countries, and would favor protecting developing countries that are least able to bear the costs of climate change. If the precautionary approach is adopted, especially by the developed countries, governmental, corporate, and personal behaviors regarding energy use and consumption would have to change in order to lessen the risk of climate change and its consequences. From the perspective of developing countries based upon ethical reasoning as opposed to decisionmaking based upon traditional economic analysis and political power, developed countries would be required to pay a so-called environmental debt caused by their historical emissions of greenhouse gases in the name of their economic development to developing countries in the form of technology transfer and debt relief in order that the latter countries would be able to provide for an appropriate quality of life for their people on a sustainable basis. This approach also would require a reduction in the per capita consumption of greenhouse gases emitted by developed countries as well as limits on population growth in the most heavily populated and affluent countries, respectively. Clearly, all of these problems cannot be understood or resolved unless the relationships among scientific, economic, and ethical knowledge and methods are understood.

Fundamentally, the problem of climate change is a problem of global ecology, but not solely in the strict scientific sense. The word *ecology* is derived from the Greek *oikos,* meaning "home" or "dwelling." In fact, ecology is all about being at home in our world, but today many humans seem to be homeless and neither at peace with themselves nor in harmony with their environment. As Ward and Dubos (1983) have pointed out, as a community of nations, we are not as yet a civilized world, even though we all have only one earth to share and care for. But to solve problems such as global climate change, the earth must truly become a common home in which an acceptable quality of life and dignity are provided for all, humans and nonhumans, a home in which we all share the promise of our common future together.

## 7. References

Adamowicz, W.L., V. Bhardwaj, and B. Macnab. 1993. Willingness to Pay and Willingness to Accept Compensation. *Land Economics* 69(4): 416-427.

Adams, R.M. 1989. Global Climate Change and Agriculture: An Economic Perspective. *American Journal of Agricultural Economics* 71(5): 1272-1279.

Agarwal, A., and S. Narain. 1991. *Global Warming in an Unequal World.* Centre for Science and Environment, New Delhi.

Agarwal, A., and S. Narain. 1992. *Towards a Green World: Should Global Environmental Management Be Built on Legal Conventions or Human Rights?* Centre for Science and Environment, New Delhi.

Angermeier, P.L., and J.R. Karr. 1994. Biological Integrity Versus Biological Diversity as Policy Directives. *BioScience* 44: 690-697.

Ayres, R.U., and J. Walter. 1991. The Greenhouse Effect: Damages, Costs and Abatement. *Environmental and Resource Economics* 1(3): 237-270.

Baes, C.F., Jr., H.E. Goeller, J.S. Olson, and R.M. Rotty. 1976. The Global Carbon Problem. ORNL-5194, Oak Ridge National Laboratories, Oak Ridge, TN.

Barry, B. 1983. Intergenerational Justice in Energy Policy. In *Energy and the Future*, D. Maclean and P.G. Brown, eds. Rowan and Allanheld, Totowa, NJ, pp. 15-30.

Batie, S.S., and H.H. Shugart. 1989. The Biological Consequences of Climate Changes: An Ecological and Economic Assessment. In *Greenhouse Warming: Abatement and Adaptation*, N.J. Rosenberg, W.E. Easterling, P.R. Crosson, and J. Darmstadter, eds. Resources for the Future, Washington, DC, pp. 121-132.

Bennett, J. 1981. Morality and Consequences. In *The Tanner Lectures on Human Values,* Vol. II, S. McMurrin, ed. University of Utah Press, Salt Lake City. pp. 45-116.

Bentham, J. (1843) 1954. The Psychology of Economic Man. *The Economic Writings of Jeremy Bentham,* Vol. 3, W. Stark, ed. Allen and Unwin, London, pp. 421-450.

Bentley, C.R. 1980. Response of the West Antarctic Ice Sheet to $CO_2$-Induced Climatic Warming. Report of DOE-sponsored meeting at Orono, ME, June.

Bergman, L. 1991. General Equilibrium Effects of Environmental Policy: A Cge-Modelling Approach. *Environmental and Resource Economics* 1(1): 43-62.

Birch, C. 1976. Creation, Technology and Human Survival. *Ecumenical Review* (January): 289.

Braden, J., and Kolstad C. 1991. *Measuring the Demandfor Environmental Quality.* Elsevier North Holland, Amsterdam.

Brown, A.W. 1977. Yellow Fever, Dengue and Dengue Hemorrhagic Fever. In *A World Geography of Diseases,* G.M. Howe, ed. Academic Press, London.

Brown, L., H. Kane, and D. Roodman. 1994. *Vital Signs 1994.* W.W. Norton & Company, New York.

Cairns, J., Jr., and B.R. Niederlehner. 1993. Ecological Function and Resilience: Neglected Criteria for Environmental Impact Assessment and Ecological Risk Analysis. *The Environmental Professional* 15: 116-124.

Care, N.S. 1982. Future Generations, Public Policy, and the Motivation Problem. *Environmental Ethics* 4: 195-214.

CCTA/WHO. 1963. *African Conference on Ancyclostomiasis.* Technical Report Serial No. 255, World Health Organization, Geneva.

Chameides, W.L., P.S. Kasibhatla, J. Yienger, and H. Levy II. 1994. Growth of Continental-Scale Metro-Agro-Plexes, Regional Ozone Pollution, and World Food Production. *Science* 264: 74-77.

Clark, J.S. 1991. Ecosystem Sensitivity to Climate Change and Complex Responses. In *Global Climate Change and Life on Earth*, R.L. Wyman, ed. Routledge, Chapman and Hall, New York, pp. 65-98.

Clark, W.C., ed. 1982. *Carbon Dioxide Review: 1982*. Oxford University Press, New York.

Cline, W.R. 1992. *The Economics of Global Warming*. Longman, Harlow, Essex.

Cohn, J.P. 1989. Gauging the Biological Impacts of the Greenhouse Effect. *BioScience* 39: 142-146.

Cousteau Society. 1991. Protecting the Rights of Future Generations. *Calypso Log*, August.

Crosson, P.R. 1989. Climate Change: Problems of Limits and Policy Responses. In *Greenhouse Warming: Abatement and Adaptation*, N.J. Rosenberg, W.E. Easterling, P.R. Crosson, and J. Darmstadter, eds. Resources for the Future, Washington, DC, pp. 69-82.

Cumberland, J.H., J.R. Hibbs, and I. Hoch, eds. 1982. *The Economics of Managing Chlorofluorocarbons: Stratospheric Ozone and Climate Issues.* Johns Hopkins Press, Baltimore.

Daily, G.C., and P.R. Ehrlich. 1990. *An Exploratory Model of the Impact of Rapid Climate Change on the World Food Situation.* The Morrison Institute for Population and Resource Studies, Stanford University, Stanford, CA.

Daily, G.C., P.R. Ehrlich, H.A. Mooney, and A.H. Ehrlich. 1991. Greenhouse Economics: Learn Before You Leap. *Ecological Economics* 4: 1-10.

d'Arge, R.C., ed. 1975. Economic and Social Measures of Biological and Climatic Change, Vol. 6, Climate Impact Assessment Program. U.S. Department of Transportation, Washington, D.C.

d'Arge, R.C., and C.L. Spash. 1991. Economic Strategies for Mitigating the Impacts of Climate Change on Future Generations. In *Ecological Economics: The Science and Management of Sustainability*, R. Costanza, ed. Columbia University Press, New York, pp. 367-383.

Dave, J.M. 1988. *Policy Options for Development in Response to Global Atmospheric Changes: Case Study for India for Greenhouse Effect Causes.* Nehru University, New Delhi.

Devall, B., and G. Sessions. 1985. *Deep Ecology*. Peregrine Smith Books, Layton, UT.

Dudek, D.J. 1991. The Nexus of Agriculture, Environment, and the Economy Under Climate Change. In *Global Climate Change and Life on Earth*, R.L. Wyman, ed. Routledge, Chapman and Hall, New York, pp. 180-200.

Ehrlich, P.R. 1989. Attributes of Invaders and the Invading Processes: Vertebrates. In *Biological Invasions: A Global Perspective*, J.A. Drake, J.A. Mooney, F. di Castri, R.H. Groves, F.J. Kruger, M. Rejmanek, and M. Williamson, eds. Wiley, New York, pp. 315-328.

Ehrlich, P.R., and A.H. Ehrlich. 1990. *The Population Explosion*. Simon and Schuster, New York.

Ehrlich, P.R., and E.O. Wilson. 1991. Biodiversity Studies: Science and Policy. *Science* 253: 758-762.

El-Sayed, M. Kh. 1991. Implications of Climate Change for Coastal Areas Along the Nile Delta. *The Environmental Professional* 13: 59-65.

(EPA) Environmental Protection Agency. 1987. Assessing the Risks of Trace Gases That Can Modify the Stratosphere. EPA 400/1-87/001A-H. Government Printing Office, Washington, DC.

Faber, M., R. Manstetten, and J.L.R. Proops. 1992. Humankind and the Environment. *Environmental Ethics* 1(3): 217-241.

Fitzroy, F. 1992. Economic Aspects of Global Warming: A Comment. *Green Values: Scottish Environmental Economics Discussion Group Newsletter* 5, Stirling, Scotland.

Flavin, C., and N. Lenssen. 1990. *Beyond the Petroleum Age: Designing a Solar Economy*. Worldwatch Institute, Washington, DC.

Flohn, H. 1982. Climate Change and an Ice-Free Arctic Ocean. In *Carbon Dioxide Review: 1982,* W. C. Clark, ed. Oxford University Press, New York, pp. 143-179.

Freeman, A.M. 1993. *The Measurement of Environmental and Resource Values: Theory and Methods*. Resources for the Future, Washington, DC.

Fujii, Y. 1990. *An Assessment of the Responsibility for the Increase in the $CO_2$ Concentration and Inter-Generational Carbon Accounts*. International Institute for Applied Systems Analysis, Laxenburg, Austria.

George, S. 1992. *The Debt Boomerang: How Third World Debt Harms Us All.* Westview Press, Boulder, CO.

Ghosh, P., and A. Jaitly. 1993. Legal Liability Versus Administrative Regulation: The Problem of Institutional Design in Global Environmental Policy. In *The Road From Rio,* P. Ghosh and A. Jaitly, eds. Tata Energy Research Institute, New Delhi, pp. 193-213.

Goodland, R.J.A., H.E. Daly, and S. El Serafy. 1993. The Urgent Need for Rapid Transition to Global Environmental Sustainability. *Environmental Conservation* 20: 297-309.

Goodpaster, K. 1994. On Being Morally Considerable. In *Reflecting on Nature: Readings in Environmental Philosophy*, L. Gruen and D. Jamieson, eds. Oxford University Press, New York, pp. 55-64.

Gornitz, V., and S. Lebedeff. 1987. Global Sea Level Changes During the Past Century. In *Sea Level Fluctuation and Coastal Evolution*, Special Publication 41, D. Nummedal, O. Pilkey, and J. Howard, eds. The Society of Economic Paleontologists and Mineralogists, Tulsa, OK, pp. 3-16.

Gravelle, H., and R. Rees. 1992. *Microeconomics*. Longmans, Harlow, Essex.

Gruen, L., and D. Jamieson, eds. 1994. *Reflecting on Nature: Readings in Environmental Philosophy*. Oxford University Press, New York.

Guha, R. 1988. Ideological Trends in Indian Environmentalism. *Economics and Political Weekly* 22(49): 2578-2581.

Hanley, N., and C.L. Spash. 1993. *Cost-Benefit Analysis and the Environment*. Edward Elgar, Aldershot, UK.

Hansen, J., and S. Lebedeff. 1987. Global Trends of Measured Surface Air Temperature. *Journal of Geophysical Research* 92: 133345-13372.

Hansen, J.E., I. Fung, A. Lacis, D. Rind, S. Lebedeff, R. Ruedy. and G. Russell. 1988. Global Climate Changes as Forecast by Goddard Institute for Space Studies Three-Dimensional Model. *Journal of Geophysical Research* 93: 9341-9364.

Hansen, J., D. Rind, A. Del Genio, A. Lacis, S. Lebedeff, M. Prather, R. Ruedy, and T. Karl. 1989. Regional Greenhouse Climate Effects. In *Proceedings of the Second North American Conference on Preparing for Climate Change*. Climate Institute, Washington, DC, pp. 68-81.

Harrison, P. 1990. Too Much Life on Earth? *New Scientist* 126: 28-29.

Hoeller, P., A. Dean, and J. Nicolaisen. 1991. Macroeconomic Implications of Reducing Greenhouse Gas Emissions: A Survey of Empirical Studies. *OECD Economic Studies* 16: 45-78.

Hoffman, J., D. Keyes, and J.G. Titus. 1983. *Projecting Future Sea-Level Rise: Methodology, Estimates to the Year 2100, and Research Needs*. Environmental Protection Agency, Washington, DC.

Hogan, K.B., J.S. Hoffman, and A.M. Thompson. 1991. Methane on the Greenhouse Agenda. *Nature* 354: 181-182.

Houghton, R.A. 1991. The Role of Forests in Affecting the Greenhouse Gas Composition of the Atmosphere. In *Global Climate Change and Life on Earth*, R.L. Wyman, ed. Routledge, Chapman and Hall, New York, pp. 43-55.

Houghton, R.A., and D.L. Skole. 1990. Changes in the Global Carbon Cycle Between 1700 and 1985. In *The Earth Transformed by Human Action*, B.L. Turner, ed. Cambridge University Press, Cambridge, UK, pp. 43-55.

(IEA) International Energy Authority. 1989. Energy and the Environment. International Energy Authority, Paris.

(IGBP) International Geosphere-Biosphere Programme. 1990. *Global Change, Report 12*. International Council of Scientific Unions, Stockholm, Sweden.

Ingham, A., and A. Ulph. 1991. Carbon Taxes and the UK Manufacturing Sector. In *Environmental Policy and the Economy*, F. Dietz, F. Van Der Ploeg, and J. Van Der Straaten, eds. Elsevier, Amsterdam, pp. 197-240.

(IPCC) International Panel on Climate Change. 1990. *Climate Change: The IPCC Scientific Assessment*, J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds. Cambridge University Press, Cambridge, UK.

(IPCC) International Panel on Climate Change. 1992. *Climate Change 1992: The Supplemental Report to the IPCC Scientific Assessment*, J.T. Houghton, G.J. Jenkins, and J.J. Ephraums, eds. Cambridge University Press, Cambridge, UK.

Jamieson, D. 1992. Ethics, Public Policy, and Global Warming. *Science, Technology and Human Values* 17:139-153.

Jamieson, D. 1994. Global Environmental Justice. In *Philosophy and the Natural Environment*, R. Attfield and A. Belsey, eds. Cambridge University Press, Cambridge, UK. pp. 199-210.

Johnson, S.P. 1993. *The Earth Summit, The United Nations Conference on Environment and Development (UNCED)*. Graham & Trotman/Martinus Nijhoff, London.

Kerr, R.A. 1993. No Way to Cool the Ultimate Greenhouse. *Science* 262: 648.

Kerr, R.A. 1994. Did Pinatubo Send Climate Warming Gases into a Dither? *Science* 263: 1562.

Keynes, J.M. (1921) 1973. *A Treatise on Probability*. Macmillan, London.

Klein, W.H. 1982. Detecting Carbon Dioxide Effects on Climate. In *Carbon Dioxide Review: 1982*, W.C. Clark, ed. Oxford University Press, New York, pp. 213-241.

Knetsch, J. 1990. Environmental Policy Implications of the Disparity Between Willingness to Pay and Compensation Demanded. *Journal of Environmental Economics and Management* 18: 227-237.

Korten, D.C. 1992. *Getting to the Twenty-First Century: Voluntary Action and the Global Agenda*. Oxford University Press, New Delhi.

Lashof, D.A., and D.R. Ahuja. 1990. Relative Contributions of Greenhouse Gas Emissions to Global Warming. *Nature* 344: 529.

Lashof, D.A., and D.A. Tirpak. 1989. Policy Options for Stabilizing Global Climate. U.S. Environmental Protection Agency, Washington, DC.

Leatherman, S.P. 1991. Climate-Induced Sea Level Rise. In *Global Climate Change and Life on Earth*, R.L. Wyman, ed. Routledge, Chapman and Hall, New York, pp. 170-179.

Lemons, J. 1985. Carbon Dioxide and the Environment: A Problem of Uncertainty. *The Journal of Environmental Sciences* 28: 60-66.

Lemons, J., ed. 1991. Preparing for Climate Change. *The Environmental Professional* 13: 1-92.

Lodge, D.M. 1993. Species Invasions and Deletions: Community Effects and Responses to Climate and Habitat Change. In *Biotic Interactions and Global Change*, P.M. Kareiva, J.G. Kingsolver, and R.B. Huey, eds. Sinauer Associates, Sunderland, MA, pp. 367-387.

Longstreth, J.A. 1990. Human Health. In *The Potential Effects of Global Climate Change on the United States*, J.B. Smith and D.A. Tirpak, eds. Hemisphere Publishing Corporation, New York, pp. 525-556.

MacLean, D. 1983. A Moral Requirement for Energy Policy. In *Energy and the Future*, D. MacLean and P. Brown, eds. Rowman and Littlefield, Totowa, NJ. 180-196.

Malinvaud, E. 1972. *Lectures on Microeconomic Theory*. North Holland, Amsterdam.

Manabe, S., and R.J. Stouffer. 1993. Century-Scale Effects of Increased Atmospheric $CO_2$ on the Ocean-Atmosphere System. *Nature* 364: 215-218.

Manne, A., and R. Richels. 1991. Global $CO_2$ Emission Reductions: The Impacts of Rising Energy Costs. *The Energy Journal* 12(1): 87-102.

Meier, M.F. 1990. Reduced Rise in Sea Level. *Nature* 343: 115-116.

Meier, C., and A. Randall. 1991. Use Value Under Uncertainty. *Land Economics* 67(4): 379-389.

Meyers, N. 1993. The Questions of Linkages in Environment and Development. *BioScience* 43: 302-310.

Mitchell, J.M. 1982. Commentary (a reply to H. Flohn). In *Carbon Dioxide Review: 1982*, W.C. Clark, ed. Oxford University Press, New York, p. 180.

Moltmann, J. 1989. *Creating a Just Future: The Politics of Peace and the Ethics of Creation in a Threatened World.* SCM Press, Philadelphia.

Nash, R.F. 1989. *The Rights of Nature: A History of Environmental Ethics*. University of Wisconsin Press, Madison.

Nordhaus, W. 1982. How Fast Should We Graze the Global Commons? *American Economic Review Association Papers and Proceedings* 72(2): 242-246.

Nordhaus, W. 1991a. To Slow or Not to Slow: The Economics of the Greenhouse Effect. *Economic Journal* 101: 920-938.

Nordhaus, W. 1991b. A Sketch of the Economics of the Greenhouse Effect. *American Economic Review* 81(2): 146-150.

Novelli, P.C., K.A. Masarie, P.P. Tans, and P.M. Lang. 1994. Recent Changes in Atmospheric Carbon Monoxide. *Science* 263: 1587-1589.

Nozick, R. 1974. *Anarchy, State, and Utopia*. Basic Books, New York.

Oppenheimer, M., and R.H. Boyle. 1990. *Dead Heat: The Race Against the Greenhouse Effect*. Basic Books, New York.

Pace, M.L. 1993. Forecasting Ecological Responses to Global Change: The Need for Large-Scale Comparative Studies. In *Biotic Interactions and Global Change*, P.M. Kareiva, J.G. Kingsolver, and R.B. Huey, eds. Sinauer Associates, Sunderland, MA, pp. 356-366.

Parry, M. 1990. *Climate Change and World Agriculture*. Earthscan Publications, London.

Peters, R.L., J.J. Armesto, B. Boeken, J.J. Cole, C.T. Driscoll, D.M. Duarte, T.M. Frost, J.P. Grime, J. Kolasa, E. Prepas, and W.G. Sprules. 1991. On the Relevance of Comparative Ecology to the Larger Field of Ecology. In *Comparative Analysis of Ecosystems*, J. Cole, G. Lovett, and S. Findlay, eds. Springer-Verlag, New York, pp. 46-64.

Pimentel, D. 1989. Ecological Systems, Natural Resources, and Food Supplies. In *Food and Natural Resources*, D. Pimentel and C.W. Hall, eds. Academic Press, San Diego, pp. 1-29.

Quine, W. 1960. *Word and Object*. MIT Press, Cambridge.

Ramamurthy, A. 1986. Gandhian Perspective on the Reconstruction of Indian Polity. In *Contemporary Crisis and Gandhi*, R. Ramashray, ed. Discovery Publications, Delhi, pp. 146-164.

Rawls, J. 1971. *A Theory of Justice*. Harvard University Press, Cambridge, MA.

Rogot, E., and S.J. Padgett. 1976. Associations of Coronary and Stroke Mortality with Temperature and Snowfall in Selected Areas of the United States 1962-1966. *American Journal of Epidemiology* 103: 565-575.

Rolston, H., III. 1988. *Environmental Ethics: Duties to and Values in the Natural World.* Temple University Press, Philadelphia.

Root, T.L. 1988. Environmental Factors Associated with Avian Distributional Boundaries. *Journal of Biogeography* 15: 489-505.

Root, T.L., and S.H. Schneider. 1993. Can Large-Scale Climatic Models Be Linked with Multiscale Ecological Studies? *Conservation Biology* 7: 256-270.

Ryther, J.H. 1969. Photosynthesis and Fish Production in the Sea. *Science* 166: 72-76.

Sagoff, M. 1988. *The Economy of the Earth*. Cambridge University Press, Cambridge, UK.

Schlesinger, M.E., and Z.-C. Zhao. 1989. Seasonal Climatic Change Induced by Doubled $CO_2$-Induced Climate Change: Preliminary Results from the OSU Coupled Atmosphere-Ocean General Circulation Model. In *Coupled Ocean-Atmosphere Models*, J.C.J. Nihoul, ed. Elsevier Oceanographic Series 40: 447-478.

Schneider, S.H. 1991. Three Reports of the Intergovernmental Panel on Climate Change. *Environment* 33: 25-30.

Schneider, S.H. 1992. Introduction to Climate Modeling. In *Climate System Modeling*, K.E. Trenberth, ed. Cambridge University Press, Cambridge, UK, pp. 3-26.

Schneider, S.H., P.H. Gleick, and L.O. Mearns. 1990. Prospects for Climate Change. In *Climate Change and U.S. Water Resources*, P.E. Waggoner, ed. John Wiley, New York, pp. 41-74.

Schwartz, T. 1978. Obligations to Posterity. In *Obligations to Future Generations*, R. Sikora and B. Barry, eds. Temple University Press, Philadelphia, pp. 3-13.

Sidgwick, H. 1907. *The Methods of Ethics*. Macmillan, London.

Singer, P. 1975/1990. *Animal Liberation*. Avon Books, New York.

Singh, M. 1993. Valedictory Address. In *The Road from Rio,* P. Ghosh and A. Jaitly, eds. Tata Energy Research Institute, New Delhi, pp. 15-22.

Smith, K.R. 1991. Allocating Responsibility for Global Warming: The Natural Debt. *Ambio* 20: 95-96.

Spash, C.L. 1993. Economics, Ethics and Long-Term Environmental Damages. *Environmental Ethics* 15(2): 117-132.

Spash, C.L. 1994. Double $CO_2$ and Beyond. *Ecological Economics* 10(1): 27-36.

Spash, C.L., and A. Clayton. In press. The Maintenance of Natural Capital: Motivations and Methods. *Environmental Values*.

Spash, C.L.,, and R.C. d'Arge. 1989. Compensation of Future Generations for Adverse Climatic Changes. Presented at the Western Economic Association International Meeting, Lake Tahoe, CA, June 18-22, 37pp.

Spash, C.L., and N. Hanley. 1994a. Cost-Benefit Analysis and the Greenhouse Effect. Ecological Economics Discussion Paper 94/6, Environmental Economics Research Group, Economics Department, University of Stirling, Scotland.

Spash, C.L., and N. Hanley. 1994b. Preferences, Information and Biodiversity Preservation. Ecological Economics Discussion Paper 94/1, Environmental Economics Research Group, Economics Department, University Of Stirling, Scotland.

Spash, C.L., and A. Young. In press. Environmental Imperatives and Renewable Sources of Energy. In *Global Oil Markets*, S. Shojai, ed. Praeger Publishers, New York.

Stevens, T., J. Echevarria, R. Glass, T. Hager, and T. More. 1991. Measuring the Existence Value of Wildlife: What Do Cvm Estimates Really Show? *Land Economics* 67(4): 390-400.

Streets, D. 1990. *Equity and Equality in the Greenhouse*. Argonne National Laboratory, Argonne, IL.

Sulzman, E.W., K.A. Poiani, and T.G.F. Kittel. In press. Modeling Human-Induced Climatic Change. *Environmental Management*.

Taylor, P. 1986. *Respect for Nature*. Princeton University Press, Princeton, NJ.

Tickell, C. 1992. The Quality of Life: What Quality? Whose Life? *Interdisciplinary Science Reviews* 17: 19-25.

Tolba, M.K. 1991. Preparing for Climate Change. *The Environmental Professional* 13: 2-7.

Trenberth, K.E., ed. 1992. *Climate System Modeling*. Cambridge University Press, Cambridge, UK.

(UNPF) United Nations Population Fund. 1991. *Population, Resources and the Environment*. UNFPA, New York.

Uphoff, N.T., ed. 1982. *Rural Development and Local Organization in Asia, Vol. I, Introduction and South Asia*. Macmillan, Delhi, 1982.

Waggoner, P.E. 1983. Agriculture and a Climate Changed by More Carbon Dioxide. In *Changing Climate*. National Academy Press, Washington, D.C.

Walker, J., and J. Kasting. 1992. Effects of Fuel and Forest Conservation on Future Levels of Atmospheric Carbon Dioxide. *Global Planet Change* 5: 151-189.

Wang, W.-C., M.P. Dudek, X.-Z. Liang, and J.T. Kiehl. 1991. Inadequacy of Effective $CO_2$ as a Proxy in Simulating the Greenhouse Effect of Other Radiatively Active Gases. *Nature* 350: 573-577.

Ward, B., and R. Dubos. 1983. *Only One Earth: The Care and Maintenance of a Small Planet*. Norton, New York.

Washington, W.M. 1992. Climate-Model Responses to Increased $CO_2$ and Other Greenhouse Gases. In *Climate System Modeling*, K.E. Trenberth, ed. Cambridge University Press, Cambridge, UK, pp. 643-668.

Washington, W.M., and G.A. Meehl. 1984. Seasonal Cycle Experiment on the Climate Sensitivity Due to a Doubling of $CO_2$ with an Atmosphere General Circulation Model Coupled to a Simple Mixed-Layer Ocean Model. *Journal of Geophysical Research* 89: 9475-9503.

Watt, W.B. 1992. Eggs, Enzymes and Evolution—Natural Genetic Variants Change Insect Fecundity. *Proceedings of the National Academy of Sciences*. National Academy Press 89: 10608-10612.

Webb, T., III. 1992. Past Changes in Vegetation and Climate: Lessons for the Future. In *Global Warming and Biological Diversity*, R.L. Peters and T.E. Lovejoy, eds. Yale University Press, New Haven, CT, pp. 59-75.

Weihe, W. 1979. Climate, Health, and Disease. In *Proceedings of the World Climate Conference*, WMO No. 537. World Meteorological Organization, Geneva, pp. 313-368.

Weiss, E. 1988. *In Fairness to Future Generations: International Law, Common Patrimony, and Intergenerational Equity*. Transnational Publishers, Dobbs Ferry, NY.

Wetherald, R.T., and S. Manabe. 1986. An Investigation of Cloud Cover Change in Response to Thermal Forcing. *Climate Change* 10: 11-42.

White, J.C., ed. 1989. *Global Climate Change Linkages*. Elsevier, New York.

Whiteman, A. 1991. A Comparison of the Financial and Non-Market Costs and Benefits of Replanting Lowland Forests. Presented to the Scottish Environmental Economics Discussion Group, Stirling, Scotland.

WHO. 1977. *Infectious Diseases: Cases and Deaths*. World Health Organization, Geneva.

Willig, R. 1976. Consumers' Surplus Without Apology. *American Economic Review* 66: 589-597.
Wilson, C.A., and J.F.B. Mitchell. 1987. A Doubled $CO_2$ Climate Sensitivity Experiment with a Global Climate Model Including a Simple Ocean. *Journal Geophysical Research* 92: 13315-13343.
WMO. 1993. *Scientific Assessment of Stratospheric Ozone, 1991*. World Meteorological Organization, Geneva.
Woodwell, G.M., R.H. Whittaker, W.A. Reilners, G.E. Likens, C.C. Delwiche, and D.B. Botkin. 1978. The Biota and the World Carbon Budget. *Science* 199: 141-146.
World Bank. 1992. *World Development Report 1992: Development and Environment*. Oxford University Press, New York.
(WRI) World Resources Institute. 1992. *World Resources 1992-1993: A Guide to the Global Environment*. Oxford University Press, New York.
Wynne, B. 1992. Uncertainty and Environmental Learning. *Global Environmental Change*: 111-127.