Climate change and biological diversity: policy implications

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POLICY IMPLICATIONS

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ABSTRACT

The earth's climate has always been changing, but current changes are unique in that they are superimposed upon a landscape which has already been greatly altered by human activity. Current knowledge is insufficient to predict the magnitude of the change, or the implications of the change on natural ecosystems, but it seems safe to conclude that some species will benefit and some will suffer from the change. Increased atmospheric CO_2 *may nurture greater plant growth, and many taxa might not suffer greatly under global warming; these include Antarctic communities, species whose sex ratio is affected by climate, species commensal with humans, and insect pests on crops. Many more species are likely to suffer, including species which are already threatened, alpine species, arctic species, migratory species, and specialized species. Policy advice in the face of considerable uncertainty about precise impacts must be based on the principle that society should pursue those actions that provide widely agreed societal benefits even if the predicted climate change does not materialize. General policies should include: direct greater research effort on the potential effects of climate change on biological diversity, and on technologies for dealing with such effects; implement action to conserve sufficient natural habitats to enable natural adaptive mechanisms to function; implement action to conserve species likely to be affected by climate change, both* ***in situ*** *and* ***ex situ****; design improved international mechanisms for dealing with the impacts of climate change on biological diversity; and support mitigating actions in other sectors. The combination of maintaining the maximum possible biological diversity; the maximum possible cultural diversity, and the greatest possible scientific endeavour would seem the most sensible approach toward dealing with the dynamic future facing humanity.*

INTRODUCTION

A sense of foreboding has crept into the public consciousness about global climate change. Of course, people have always been concerned about the weather -- it may be the world's second-most popular topic of conversation. But recent aberrant climatic episodes -- droughts in the US and Canada, vicious cyclones in the Caribbean and Southeast Asia, record winds in England, and so forth -- have been coupled with scientific evidence that the climate may indeed be changing at a rapid rate (Houghton and Woodwell, 1989).

The consensus (though by no means unanimous) opinion of climatologists is that the so-called greenhouse effect, due to the observed accumulation of carbon dioxide, methane, nitrous oxide and chlorofluorocarbons in the atmosphere, is likely to raise mean world temperatures by about 2°C by 2030 and mean sea levels by around 30-50 cm on a comparable time scale (Warrick, *et al.*, 1988). By the end of the next century, global average surface temperatures are predicted by some to increase by 2-6°C with an attendant rise of sea level of 0.5-1.5m; such a change could be 10 to 50 times as fast as the natural average rate of temperature change since the end of the last glaciation (Schneider, 1989).

Some experts think that hurricanes will be more frequent and be 40-50% more destructive (Emanuel, 1987); droughts will be more protracted; heat waves will be longer and hotter; and rainy periods will be more severe. The great ice sheets of Antarctica could either grow or shrink (Frolich, 1989). All of these are symptoms of fundamental changes in the energy system of the world, connected through a complex web of interactions, none of which are yet fully understood by scientists.

Rapid changes in climate may characterize fundamental shifts from one climatic state to another. For example, Dansgaard, *et al.*, (1989) found that the last glacial cold period (known as the "Younger Dryas") ended abruptly 10,700 years ago, suggesting that in less than 20 years the climate in the north Atlantic region transformed into a milder and less stormy regime as a consequence of a rapid retreat of the sea ice cover. A warming of 7°C in South Greenland was completed in about 50 years, and evidence from ice cores in Tibet suggest that the transition from the late glacial stage to the Holocene may have occurred over a 40-year period which involved the drying of major Tibetan lakes and high winds which deposited loess hundreds of feet thick across central and eastern China (Thompson, *et al., 1989).*

Even more rapid changes can be brought about by geological forces such as volcanoes, though it is not clear whether such changes bring about basic shifts in the equilibrium climate state. For example, the Indonesian volcano Tambora spewed 100 billion cubic metres of ash, leading to the year without a summer in 1816 in New England and Northern Europe; snow and frosts in June and July brought hardship to both regions, dropping average temperatures 5°C (Kerr, 1989).

With rapid climatic changes came equally rapid changes in sea level. Tooley (1989) reports on a body of evidence suggesting that sea levels may have risen by over 40 mm per year over a hundred year period about 8,000 years ago, and that catastrophic release of turbulent meltwater captured behind North American glaciers could have raised the sea level by 23 cm in as little as a few weeks.

So it is apparent that life on earth has been subject to both gradual and sudden climatic changes. Four interconnected factors set the current phase apart from all preceding ones: first, human consumption of natural resources and conversion of natural forests and other habitats to other purposes appear to be forcing the change; second, the human population is at an all-time high, so any significant change is likely to have major effects on people; third, natural ecosystems are now scattered among human agricultural and other cultural landscapes, making it difficult for natural systems to adapt by moving with the climate; and fourth, the populations of many species have already been so reduced by human actions that little resilience remains, leaving them vulnerable to the additional stresses that climate change would bring.

While the earth has benefited from a greenhouse effect for hundreds of millions of years -- it is what makes the planet habitable -- the effect is now becoming intensified to the extent that some habitats may become unsuitable for the species currently living there at a time when those habitats are so isolated by surrounding agricultural lands that the wildlife has no other place to go (Strain, 1987). In the coastal zone, rising sea level could outstrip the rate of growth of coral reefs, and increases in water temperature could further threaten these extremely rich habitats (Ray, *et al.*, 1988). Sea level rises could also flood salt marshes and dune systems, and compress zones of coastal mangroves so much that coastlines are no longer adequately protected from waves and storm surges.

Projected climate changes for the next century would have major impacts on forests, biological diversity, water resources, sea level, agriculture, human health, transportation, energy, and many other sectors. These in turn will certainly have effects on civilization, and the faster changes occur, the more difficult it becomes to predict the consequences for both society and the ecosystems upon which it depends.

In seeking to deal with changes that may be unprecedented in human history, and which have such profound importance to human well-being, policy-makers and planners are faced with serious difficulties. How certain are the predicted changes? What are the possible impacts on natural ecosystems? What are the implications of such change for government conservation policies? What can be done today to deal with changes that may or may not come tomorrow? Major investments are being made to seek answers to these questions (see, for example, Holdgate, *et al.*, 1989; IPCC, 1994). This paper will seek to provide elements for policy responses as they deal with biological diversity, while realizing that such elements can be only part of the overall body of policies that society requires to adapt to change.

THE LIKELIHOOD OF THE PREDICTED CHANGES

Climate is influenced by a wide range of geological and solar forces. Continental drift causes major changes by affecting ocean currents and the global atmospheric circulation, and pulses of tectonic plate movement may produce significant bursts of volcanic activity that eject sufficient aerosols to affect the global climate. Some evidence indicates, for example, that the "El Niño" phenomenon may be related to the spreading of tectonic plates just west of Easter Island, where frequent earthquakes and volcanic activity generate heat which warms the air, which in turn causes the drop in eastern Pacific atmospheric pressure that an El Niño event requires.

At the multimillenial scale, the variations in irradiance of the earth, resulting from slow changes in the sunearth geometry (the so-called Milankovitch variations) control the timing of ice ages and interglacials. Sunspots also ebb and flow and have long been credited as a source of cyclic climatic changes, and periodic changes in climate produced by the tidal effects of the moon affect both rainfall and crop yields over a period of 18.613 years; the sea level varies over the same cycle (Curry, 1988).

A wide range of evidence, including a continuous isotope temperature record for the past 160,000 years from the Vostok ice core in Antarctica (Jouzel, *et al.*, 1987), demonstrates that climate follows a variety of cycles of different wave-length, with the harmonics leading to widely varying climates over time; more detailed records for the past 18,000 years indicate both cycles and trends (COHMAP, 1988). Only some of these cycles appear to have any very direct relationship with atmospheric carbon dioxide.

For most of the history of our genus the climate has been far less benign than it is today. According to Bryson (1988), over the last million years only 68% of the time has been as free of continental glaciers as the present, with interglacial episodes lasting 9,000 to 12,000 years. We have been in the present interglacial for about 10,800 years, suggesting that without CO_2 increase we might well be heading for another glacial period.

Climate change is a global phenomenon, often involving inscrutable linkages over which humans have little control; some of these may cause decreases in CO_2, rather than increases. To give but a few examples of such linkages:

- The planetary circulation is subject to abrupt transitions, affecting such phenomena as onset of seasonal migration of the Asian Monsoon and changes in the jet stream. Changes in some of these atmospheric circulation patterns have already been linked to climate patterns during the Little Ice Age (1480-1890) (Crowley and North, 1988), long before industrial civilization started burning significant amounts of fossil fuels.

- Large-scale variations in the amount of snowfall over Eurasia in springtime are linked to the subsequent strength of the Asian summer monsoon and have a strong connection with the atmospheric field over North America; snow cover effects subsequently alter other climatic fields known to be intimately associates with the El Niño phenomenon (Barnett, *et al.*, 1988).

- The 1988 summer drought in the US involved a pronounced and distinctive wave-train of anomalies in the atmospheric circulation that appeared to emanate from anomalously low temperatures in the tropical Pacific (the reverse of the El Niño phenomenon, sometimes called "La Niña") (Trenberth, *et al.*, 1988; Palmer and Brankovic, 1989).

- The "ozone hole" observed in the austral springtime appears to lead to a temperature decrease in the lower Antarctic Stratosphere in mid-October (Kiehl, 1988). Correlations have been found between the Amazon river discharge and the Tropical Pacific Climate Cycle (Richey *et al.*, 1989), even though no very direct link exists between the two systems; and the Pacific helps to drain the Nile, which in fact flows into the Mediterranean (MacKenzie, 1987).
- The recent increase in chlorophyll in the North pacific in the summer has been accompanied by an increase in winter winds and a decrease in sea surface temperatures, suggesting that long-term fluctuations in atmospheric characteristics have changed the carrying capacity of the central Pacific epipelagic ecosystem (and presumably other marine ecosystems as well) (Venrick *et al.*, 1987).

The geological and planetary factors which cause climate change are still in operation, but possible human influences on the climate are greater than ever before. The most dramatic symptom is the very clear trend in the increase in atmospheric carbon dioxide and other "greenhouse gasses", which has gained considerable attention because human behaviour is a new contribution to climate which is -- at least in theory -- controllable.

Possible human-induced global cooling

Human factors could also lead to a global cooling. Sagen *et al*. (1979) suggest that humans have made substantial contributions to global climate changes during the past several millennia, and perhaps over the pat million years, primarily due to fire and the sending of particulate matter into the atmosphere. An increased rate of forest fires (which is a combination of natural and human phenomena) can have significant feedbacks into the climate system. Smoke emitted from forest fires in northern California in September 1987 was trapped in a valley by an inversion for three weeks. Daily maximum temperatures on the valley floor were more than 15°C below normal for one week and more than 5°C below normal for three weeks. The smoke strengthened the inversion by preventing surface warming by solar radiation, thereby involving smoke trapping and surface cooling in a positive feedback loop (Robock, 1988). In general, the abundance and frequency of fires increases in dry periods, especially when early successional stages are breaking up; the warm, dry periods, especially when early successional stages are breaking up; the warm, dry twentieth century climate would have produced substantially greater forest fires in the absence of fire suppression, which might have produced sufficient smoke to slow climate warming (Clarke, 1988).

Perhaps even more dramatic is the image of "nuclear winter", whereby even a moderate exchange of nuclear weapons would eject so much particulate matter into the atmosphere that sunlight would be essentially blocked, thereby leading to another ice age (Schneider and Thompson, 1988). while the likelihood of a nuclear exchange among superpowers has receded somewhat in recent months, nuclear weapons technology is still being perfected and more governments are gaining access to these weapons; complacency in the face of such a grave danger would appear unjustified, and a political miscalculation could conceivably replace global warming with the even worse curse of a nuclear winter.

Estimating the magnitude and rate of climate change

The feedback mechanisms that affect climate are still so poorly understood that estimating global temperature increases accurately is difficult; projections of the increase in global equilibrium temperature in response to a doubling of CO_2 range from about 1.5° to 5.5°C (Schneider, 1989). Slingo (1989) compared 14 general circulation models and found a three-fold variation in global climate sensitivity, caused largely by differences in the cloud feedbacks. "The substantial sensitivity of climate models to the details of their formulation", he says, "and the fact that 14 models give 14 different answers for the cloud feedback, show that we are far from the goal of accurate predictions of future climate change".

The effects of the deep oceans are even more difficult to model. Most oceanographers believe that the deep oceans would respond slowly -- on time scales of many decades to centuries -- to climatic warming at the surface, and also act non-uniformly in space and time. Therefore, the oceans, like the forests, would be out of equilibrium with the atmosphere if greenhouse gases increase as rapidly as typically is projected (Schneider, 1989). Further, the oceans may be able to compensate, at least partially, for increased CO_2. The major source of cloud-condensation nuclei over the oceans appears to be dymethylsulphide produced by planktonic algae in sea water; doubling the number of such nuclei would be sufficient to counteract the warming due to doubling of atmospheric CO_2, so biological regulation of the climate is possible through the effects of temperature and sunlight on phytoplankton population and dymethylsulphide production (Charlson *et al.*, 1987).

In conclusion, while scientists are virtually unanimous that the climate is getting warmer, current models of climate change give widely variable rates of change; any of a number of "external factors" can throw projections far off course. Scientists are unlikely to ever be able to give precise predictions of the future climate, and predictions become considerably less reliable when applied to specific areas. Some experts fear that even with a great intensification of effort, the effects of the rise in concentration of the greenhouse gases will come largely as surprises (Broecker, 1987).

Such uncertainty underlies the difficulty in providing policy advice to governments which are typically motivated by political factors and such intangibles as "the mood of the public". that mood is today very much in support of strong action, stimulated by perceived symptoms of global warming. What, then, are scientists and policy-makers to do with this opportunity?

POSSIBLE IMPACTS OF CLIMATE CHANGE ON NATURAL ECOSYSTEMS

The first step in seeking an answer is to ensure that the decisions being taken today are based on as complete information as possible. This involves estimating how natural ecosystems are likely to respond to the changes which are predicted to take place. As has been suggested above, climate has been constantly changing throughout the earth's geological history; the species that have survived until the present are adapted to the particularly rapid changes that have characterized the past few million years. European and North American species have ebbed and flowed with the Great Ice Age glaciers; sea level changes in southeast Asia have repeatedly attached and separated Java, Borneo, and Sumatra with the mainland; New Guinea has been alternately connected and disconnected with Australia; and the great rainforests of Amazonia appear to have varied with the climate, creating forest "refugia" during parts of the Pleistocene (Prance, *et al.*, 1986).

Range, population, and community structure are constantly changing for all species, due to a wide variety of factors; but factors ultimately caused by humans have pushed many species to the verge of extinction even without climate change (IUCN, 1986). If climate changes as quickly as some predictions suggest, the adaptability of many species will be sorely tested, and many could become extinct. Other species could be stranded in environmental conditions to which they are not adapted, forced either to change their behaviour or to become extinct. Such changes may characterize the major extinction events which have occasionally hit the planet, and indeed past major climatic changes seem to be closely associated with major extinctions (Crowley and North, 1988).

As with any change, climate changes will enable some species to gain and some to lose, at least in the Darwinian sense of measuring success by gene flow. Exact predictions are very risky, but some general trends seem to have considerable support from ecology (Peters and Darling, 1985; Paine, 1988). The following section indicates some of the lines of investigation that will require far more attention in the coming years if the necessary ecological information is to become available to support policy decisions.

Fig. 1: Schematic classification of plant formations in correlation with climatic factors (from Holdridge, 1967).

General principles

1. MacArthur (1972) has derived some broad rules about how ecosystems respond to climate change, suggesting that a change of 3°C can lead to a shift in habitat type of roughly 250 km in latitude or 500 m in elevation, assuming sufficient continuity of available habitat to allow such moves. Holdridge (1967) has devised a system of latitudinal regions, altitude belts, and humidity provinces which correlates plant formations with climatic factors (Fig. 1); this can be used to predict the location of major vegetation type given a particular moisture regime. The effects of climate change may be particularly dramatic in the major ecotones, where adjacent biomes come together (Holdgate, *et al.*, 1989); the coastal zone, the taiga-tundra ecotone, and the forest-savannah ecotone is where major shifts in vegetation belts may first become apparent.

2. However, the geographical distributions of species are altered individually, not in community units; outside of islands, few species share precisely the same range. Each species will respond according to its own capacities and it is impossible to predict with much precision the composition of the new communities that may form (Connor, 1986). Rather than a simple northward or uphill shifting of ecosystems with all of their inhabitants, climate change will bring a complete reorganization of biological communities. Further, because species are interrelated, any advantage falling to a given species in a relatively closed system will affect other species in ways that are not always predictable.

3. A major mechanism by which animal species will adapt to climate change is reproduction, including such variables as litter size, birth interval, number of surviving young, rate of spontaneous abortion, rate of delayed implantation of ova, and dispersion of offspring. Among plants, increasing the atmospheric carbon dioxide concentration under experimental conditions alters the growth rate of reproductive potential of plants, and must ultimately affect interactions at the community level and beyond (Strain, 1987). Mature animals and plants are much more likely to survive a crisis than either the younger stages or the senescent ones (though this may not be the case for coastal species with planktonic larvae and freshwater insect species with short-lived aerial young). While the senescent individuals are typically no longer reproducing, the loss of young means that the population will have greater difficulty replacing its older generation as it dies.

4. Temperature is unlikely to be the most important influence on the forest community. Changes in rainfall and seasonality may be far more influential, particularly if they cause major changes in the production of fruit by certain key species. Further, the responses of forests to climate change may depend as much on the indirect effects of climate and vegetation on soil properties as on the direct effects of temperature on tree growth; if soil chemistry controls a certain species distribution, then predicted shifts in temperature and precipitation may not cause a shift in species range, and atmospheric pollution may become a key factor in determining species distribution. The heterogeneity of the landscape, particularly the distribution of various soils, is therefore an important factor determining forest responses to climate change (Pastor and Post, 1988) and may delay an effect for many years, even allowing climatic trends to change direction again.

5. Large ecosystems cannot be expected to react quickly to climate change, except when the change is accompanied by other ecological factors such as fire or disease. Soil types change very slowly, and many trees are very long-lived and will survive for hundreds of years even if they do not reproduce. Further, the species that exist today are already adapted to the fairly rapid climate changes that have characterized the past two million years and many species ranges appear to be affected more significantly by factors such as competition than by climate change. MacArthur (1972) has discussed this point in some detail, pointing out that many species tend to be persistent once they have become established, so which will become established in "new" communities will be greatly influenced by the ones which have survived from the "old" communities. The only safe conclusion seems to be that under conditions of changing climates, variable responses by the resident plants and animals are to be expected and these are likely to be highly unpredictable given our current state of knowledge.

Taxa which may benefit from climate change

The following groups of species may be able to benefit from climate change, or at least be able to adapt to the predicted changes without suffering catastrophic losses in genetic diversity. However, any possible advantages could be cancelled rather quickly by the effects of inappropriate human activities on the habitats of these groups.

Plants. The forcing mechanism receiving greatest attention today is increasing carbon dioxide, and at least some plants thrive on a CO_2 rich atmosphere. In three subalpine conifers (*Pinus flexilis, P. Longaeva, P. aristata*) greatly increased tree growth rates observed since the mid-19th century exceed those expected from climatic trends but are consistent in magnitude with global trends in CO_2, especially in recent decades (LaMarch, *et al.*, 1984). In laboratory studies, increasing the concentration of CO_2 to 1000 parts per million has produced higher yielding wheat, bigger sugar beets and radishes that were big enough to eat in half the usual time. Other observations suggest that when the concentration of CO_2 is high, the stomata partially close, thereby reducing the loss of water; plants become more efficient in their use of water, so shrubby vegetation may spread into more barren regions of east and southern Africa, Saudi Arabia and Australia. That said, researchers know very little about the responses of vegetation rather than a single leaf or plant to an increase in CO_2 (Fajer, *et al.*, 1989). The topical forests, whose growth is more closely linked to water availability and seasonality than in temperate forests, could become more vulnerable at their drier margins to the encroachment of grassland or savannah and the associated human effects (Holdgate, *et al.*, 1989), including fire.

Insect pests on crops. But while plants fertilized with carbon dioxide might be bigger and grow faster, they are less nutritious so caterpillars that eat plants grown under these experimental conditions have to eat more to achieve their normal rate of growth. If this laboratory observation is a general effect, insect pests will become a bigger threat to crops (Paine, 1988). Locusts, aphids, and moths become more active and more fecund as temperature or humidity rises, which has sobering implications for agriculture.

Long-lived trees. Many trees can survive quite long periods in climates which are clearly inappropriate for their reproduction. But since climate is cyclical, they can await the return of suitable conditions. In the single lifetime of one tree, climate could easily change as much as 5 to 8°C, and has. Trees which disperse light, wind-blown seeds or drop seeds carried by animals will have a better chance of dispersing with the climate than the more sedentary trees which drop their seeds to the forest floor to lie dormant until a gap appears in the canopy.

Species commensal with humans. Rats, mice, sparrows, pigeons, crows, cockroaches, and other species that have learned to live with humans can be expected to respond well to any change, having already proved their resilience and opportunism. Their habitats and food supplies are likely to continue to expand.

Antarctic communities. While they are adapted to the current cold conditions, Antarctic species might be able to adapt to warming that would lengthen reproductive seasons or increase food supply; because of the isolation of Antarctica, they would be unlikely to face competition from invading species moving south. However, it appears that at least some species of plankton are highly sensitive to increased ultraviolet radiation, so the observed damage to the tropospheric ozone layer may have significant deleterious effects on the entire Antarctic food chains which are built on plankton (El-Sayed, 1988).

Species which can reproduce quickly when the opportunity presents itself. Such species known as "r strategists" by ecologists can take advantage of climate change. For example, the 1982/1983 El Niño gave Galapagos ten times as much rain as it had ever had in recorded history, so most plant species dramatically increased seed production and caterpillars became extremely abundant. Ground finch species (*Geospiza* spp.) responded to the increase in food supply be females producing up to 10 clutches of eggs, instead of the usual one to five clutches; the large number of young resulted in increases in the population size by a factor of 4 (Gibbs and Grant, 1987). Another group in this category is parasites, which are colonizing organisms whose success depends on their capacity to adapt swiftly to new conditions; for example, tropical insect-borne diseases such as malaria and filariasis may be able to expand their ranges.

Species whose sex ratios are affected by climate. For a number of reptiles, the sex of the offspring is affected by the temperature at which the eggs are incubated ("environmental sex determination"). Higher temperatures produce more males of alligators and crocodiles and more females of some turtles, thereby enabling sex ratios to be adjusted in response to particular environmental conditions (Head *et al.*, 1987); some fish, lizards, and invertebrates are also subject to environmental sex determination. A warmer world therefore, may affect the sex ratios of a number of species, though of course they could change the temperature of the nest by shifting location to a shadier area, or breeding in different seasons. Longer reproductive seasons at the margins of species ranges could well yield considerable range extensions, provided habitat were available.

Taxa which may be threatened by climate change

The following groups of species are unlikely to benefit from climate change, and the predicted changes may bring about catastrophic losses in genetic diversity (or even extinction).

Rare or threatened species. Nearly 22,000 species are already threatened, including about 10% of all birds and mammals (McNeely, *et al.*, 1989). These species have already been reduced to such low population levels that extraordinary conservation action is required; many suffer from a wide range of threats, and the additional stress of climate change could lead rather quickly to extinction. many of these species are endemic to relatively small areas, often as a result of past climate changes or adaptation to specialized habitats. They would be less likely to have any populations in areas of suitable habitat after a climate change than those whose distributions is more widespread. Some species are confined to protected areas, and these are often the endangered species of particular interest to society at large. Such narrowly endemic species will be especially vulnerable to habitat changes, particularly in the case where their habitats are isolated by incompatible human uses of the surrounding lands.

Migratory species. Migratory species need to have appropriate conditions throughout their migratory pathways, so if wetlands, for example, dray out during critical times of the year for the migratory species, then the entire migratory system may break down. in the Northern Hemisphere, shorebirds such as sanderlings and plovers spend the winter in South Africa and travel north to breed in the Arctic in summer, stopping in Delawere Bay to feed on the eggs of horseshoe crabs, which arrive and lay their eggs at the same time each year. If the timing of horseshoe crab egg-laying were to be disrupted, the effects on the migrants could lead to a late arrival in the Arctic, missing the summer population explosion of the Arctic insects which is required to provide the hatchlings with sufficient food (Paine, 1988). In the tropics, altitudinal migrants might also be at risk if high altitude breeding habitats are diminished.

Species dependent on the timing of ice melting. Under normal conditions, snow and ice melt in northern Europe over a period of several weeks, with the acidic meltwater draining through the soil, which in turn neutralizes it before it runs off into lakes and rivers. If the melting were to occur earlier and faster, the meltwater would run over the soil and into rivers, introducing a flood of acid water at a time when many animals are at their most vulnerable stage -- eggs or fish fry for example. In addition, less water would be available in the following months, and with the warmer summer, water is likely to be in short supply. The pools and shallow lakes of the tiaga and tundra -- home to large populations of migratory water birds -- may become a far less productive habitat (Paine, 1988).

Arctic communities. Most models indicate that the polar regions are likely to be subject to much greater temperature increases than those closer to the equator, so species that are adapted to cold climates (either because of food supply or lack of competition) may need to migrate northwards; but if they are already in high latitudes, they may not have much available habitat. Many of Europe's most productive wildlife habitats are in the far north, where algae, bacteria, and other microscopic organisms grow on the undersides of sea ice during the spring; as the ice breaks up with the approach of summer, the organisms are released into the water where they support a whole series of food webs that include such large species as whales, polar bears and seals. An increase of 5°C in the next 50 years will melt even the permanent Arctic ice (Paine, 1988), bringing fundamental changes to polar ecosystems. If an ozone hole becomes established over the North Pole, the implications could be even worse.

Peripheral populations. Populations located near the edge of a species range may already be "pioneers", seeking to expand the range of the species at the very limits of ecological suitability; more favourable climate will enable them to prosper, while less favourable climate could cause their extirpation, depending upon their competition. In many cases, this could be a toss up. Barton and Hewitt (1989) summarized a survey of over 170 hybrid zones, narrow regions in which genetically distinct populations meet, mate and produce hybrids. Hybrid zones are especially well suited for testing the view that adaptation involves a "shifting balance" between selection on individuals and selection on the whole populations. For example, the fire-bellied toad *Bombina bombina* and yellow-bellied toad *B. variegata* interbreed freely in a narrow zone that runs for 1,000 km through eastern Europe, but they differ in mating call, warning coloration, life history, preferred habitat, enzymes and mitochondrial DNA. Climate change may well tip the balance to the favour of one or the other of the species in such hybrid zones, especially since these are often species with good colonizing ability.

Genetically impoverished species. Genetic diversity enables species to adapt to change, so species that are genetically impoverished are likely to suffer. Their genetic impoverishment may be due to very small population sizes (as in blackfooted ferrets) or to historical factors (as in the cheetah). Major crops which have been genetically selected for certain characteristics may find it difficult to adapt to the changes.

Specialized species. Species which are dependent on a narrow range of habitat conditions such as the dependence of the giant panda on bamboo, or certain species of birds which need old-growth forests to provide nesting sites, may be unable to adapt to fundamental changes to their habitats caused by climate change. Using Galapagos again, while the ground finches prospered, oceanic productivity was low in the 1982/3 El Niño, so many seabirds did not breed, including the Galapagos penguin (*Spheniscus mendiculus*) and the flightless cormorant (*Nonnopterun harrisi*). The cormorant and penguin populations were reduced by 49% and 77"% respectively; by 1988, the cormorant had recovered but the penguin population remained very low (Valle and Coulter, 1987).

Montane and alpine communities. Many alpine species are already relictual, having been isolated by past climate changes. If climate change forces them further uphill, they will occupy smaller areas or even be forced off the top of the mountain; for example, species which depend on alpine grasslands such as marmots, pikas, and some mountain ungulates would find it difficult to survive if grasslands were invaded by shrubs and trees, as boreal forests climb in elevation. Considerable evidence also indicates that mountains lose species faster than they gain them. Brown (1971), for example, showed that in 17 isolated mountain groups in the Great Basin of North America all had lost at least one of the 13 species of small mammal that had colonized the mountain during the Pleistocene before the climatic barriers that currently isolate them were erected, and most had lost at least half their mammal species; none of the species lost had been replaced by new immigrants.

PROTECTED AREAS AND CLIMATE CHANGE

Protected areas provide one of society's strongest tools for conserving biological diversity, so they should be a major concern to society during a period of rapid climatic change. They can offer refugia to species and communities which can no longer survive elsewhere, but that may be able to repopulate areas which subsequently become suitable habitat as climate changes again. They can provide the source of genetic diversity which agriculturalists will find increasingly important as they seek to enable domestic species to adapt to climate change. They can help maintain productive water cycles, mediating both floods and droughts.

However, protected areas will also face challenges. If they are "islands" of habitat, protected areas can be expected in the long run to support only those species that have an area requirement smaller than the reserve (Newmark, 1986). Given the trends in human land use, habitat adjacent to most protected areas will become increasingly inhospitable to mammalian dispersal unless innovative measures are taken. Most protected areas are already too small to conserve most species of large trees, carnivorous birds, and large mammals by themselves, so far larger areas need to be managed to conserve biological diversity. The strictly protected reserve would then form the core area of a much larger landscape which contains a range of human uses, all managed with the broad objectives of maintaining biological diversity and developing human uses of the land which can be sustainable in the long run (McNeely *et al.*, 1989). Such large areas will be better able to adapt to climate change by enabling a variety of microclimates to shift with the conditions, with the full range of species sorting themselves out accordingly.

In addition to large protected areas (or those located within a larger landscape which includes significant areas of land being used in ways that enable wild species to survive), protected areas which cover a wide altitudinal gradient may be better able to contribute to maintaining biological diversity than those which are relatively flat, because generally speaking areas on mountains cover a wider range of habitat types. In attempting to assess how the world's protected areas are distributed by altitudinal range, a review was made of all protected areas of over 1000 ha in size, in IUCN Categories I to V (strict nature reserves, national parks, national monuments, managed wildlife reserves, and protected landscapes) (IUCN, 1984). Of the 4,518 sites meeting the first two criteria, altitudinal range data were available for 2,290 sites (51%). The results are presented in Table 1, showing that some 686 (30%) of the sites cover more than 1000 metres in elevation; following MacArthur's (1972) suggestion that a change of 3°C can lead to a shift in habitat type of roughly 500 m in elevation, and keeping in mind the prediction of a 6°C increase in global climate, such areas appear to contain sufficient altitudinal variation to accommodate the climate changes foreseen in the coming century.

Table 1: Altitudinal range of protected areas

Altitudinal Range (in metres)								
Biogeographic Realm	0 999	1000 1999	2000 2999	3000 3999	4000 4999	5000 5999	6000 6999	Total
Nearctic	171	41	27	4	6	2	2	253
Palaearctic	423	146	49	25	6	4	4	657
Afrotropical	319	50	14	2	2	-	-	387
Indomalaya	346	92	21	7	-	-	-	466
Oceania	23	8	1	2	2	1	-	37
Australia	85	26	-	-	-	-	-	111
Antarctic	76	21	4	3	-	-	-	104
Neotropical	161	51	34	21	5	3	-	277
Totals	1604	435	150	64	21	10	6	2290

SOCIETY, BIOLOGICAL DIVERSITY, AND CLIMATE CHANGE

While ecological effects on biological diversity could well be traumatic, they will only amplify the impacts that are already being imposed on natural systems by humans. Unfortunately, as human populations and levels of consumption of natural resources continue to rise, so too will the impacts of humans on natural systems. Major changes in the ecological-economic-political-social feedback system can reasonably be expected to follow major changes in climate, thereby precipitating major changes in human civilization.

This is nothing new. Climatic variation has often had dramatic impacts on human and biotic societies of the pat, often being implicated in the fall of ancient civilizations (Bryson, 1988). Modern society, for all its technological marvels, is not immune to climatic impact. In fact, it may well be that our highly specialized society, dependent as it is on a very wide range of resources, energy, alliances, transport, and so forth, is more vulnerable to change than are local communities that control most of the main inputs to their lives. Considerable social consternation could be generated when projected shifts affect agricultural production, particularly since the cause was economic activities (i.e., CO_2 production) that directed differential costs and benefits to various groups. In essence, greenhouse gas-induced environmental changes create an issue of "redistributive justice" (Schneider, 1989). The social instability that is likely to follow from such social consternation means that we must generate very robust systems of resource management, able to survive the major social changes which may well arise.

It would therefore appear reasonable to make every effort to promote local adaptations to local resources; in other words, to promote the conservation of cultural diversity as well as biological diversity.

Building conservation institutions in times of social turbulence will be difficult, especially because attention will be diverted elsewhere and many demands will be put on scarce resources. Immediate human needs, such as dealing with the droughts, famines, and floods, will draw much attention, especially because the world is now linked through television and human catastrophes are more dramatic than the more insidious effects of climate change on natural ecosystems. Generating the very considerable funds that would be required for effective measures to mitigate new influences on wildlife will be a daunting task in the face of these more pressing immediate demands.

It may well be, then, that the most productive approach to conserving biological diversity in highly stressful times will be indirect, seeking to ensure that agriculture, forestry, and other human land uses are based on sound ecological principles, along the lines advocated by the World Commission on Environment and Development (WCED, 1987, and Agenda 21).

IMPLICATIONS OF CLIMATE CHANGE FOR CONSERVATION POLICIES

The major policy conclusion from the above discussion is that society should pursue those actions that provide widely agreed societal benefits even if the predicted climate change does not materialize. A second general point is that no conservation activity should be undertaken without some explicit consideration of the potential future impacts of climatic change. And the following policies will be most effective when they are carried out as part of a larger body of policy aimed at the larger goal of seeking forms of human society which are sustainable in the long run.

The following policy elements would both help maintain biological diversity and contribute to the overall social, economic, and political objectives advocated by the Climate Change and Biodiversity Conventions.

Direct greater research effort on the potential effects of climate change on biological diversity, and on technologies for dealing with such effects

- Develop the capacity to identify those species and communities that are most likely to suffer from climate change, develop practical field methods for assessing the viability of their populations, and design ways to monitor the effects of management actions on species and habitats.

- Launch an urgent research programme to assess traditional cultural mechanisms for adapting to changing environments, with a view to ensuring that local people are given greater responsibility over the resources on which they depend; and conduct research on mechanisms for enhancing greater local self-reliance.

- establish a set of long-term research areas, possibly based on biosphere reserves in collaboration with UNESCO, to assess the impacts of possible climate changes on species and ecosystems; such research should address, among others, the processes of succession under changed climatic regimes.

- Promote a major increase in research on species and ecosystems which are adapted to major climatic changes or marked seasonality, such as seasonally inundated swamp forests, systems periodically affected by drought, and taiga-tundra systems.

- Develop methodologies for the intensive management of species. Such management might be required to mitigate the effects of climatic change, including the technology for manipulating breeding through techniques such as artificial insemination, and the possible influences of climate on assessments of population viability analysis (PVA).

- Conduct research on the economic impact of climate change on biological diversity, aimed at ensuring that sufficient investments are made in conservation to mitigate the negative effects of the industrial activities which are causing climate change.

Implement action to conserve sufficient natural habitats to enable natural adaptive mechanisms to function

- Concentrate efforts on preserving the conditions that foster biological diversity in general, thereby enabling natural communities to adapt to change; special attention should be given to maintaining the capacity of species to disperse to new areas.

- Ensure that protected areas are managed in ways that encourage local support for them, thereby enhancing their chances to survive under any future scenario. Such local support for protected areas can be increased through such measures as education, revenue sharing, participation in decisions, complementary development schemes adjacent to the protected area, and, where compatible with the protected area's objectives, access to some of the resources in the area (McNeely, 1992).

- Carry out systematic reviews to identify the most important remaining natural habitats, and to specify the most appropriate ways to manage such areas.

- Give particular attention to areas containing endemic species, or which support a high diversity of species; and ensure that species are contained in more than one protected area, thereby increasing their chances of adapting to change.

- Develop guidelines for identifying when habitats need to be "improved" through such techniques as enrichment planting and creation of artificial water sources, and how such habitat manipulations can best be carried out.

- Develop the capacity to manage biological diversity in natural areas which are not strictly protected, including through techniques such a buffer zones, natural corridors, etc.

- Design and hold training courses for protected area managers on the subject of coping with climate-induced changes.

- Seek opportunities for adding new land to the conservation estate, as climate-related changes lead to abandoned agricultural land or create new coastal wetlands. It has been suggested that in Europe specifically, the EC set-aside programme under the Common Agricultural Policy could be implemented with climate change in mind.

- Ensure that funds are available from the greenhouse gas-producing countries to the tropical countries whose protected areas are going to require additional funds for management.

Implement action to conserve species likely to be affected by climate change, including both in situ and ex situ efforts

- At the species level, adopt management strategies which will enable vulnerable species to adapt to the stresses of a changing and uncertain environment. The first step is to identify which species are vulnerable, and establish criteria for determining which species most merit a public investment in their survival.

- Prepare contingency plans to adapt to such changes as may arise.

- Maintain populations of key species in captivity, for subsequent reintroduction.

- Develop guidelines for identifying and controlling rapidly increasing populations that are advancing at the expense of other populations.

- Develop the capacity to transplant key species.

Design improved international mechanisms for dealing with the impacts of climate change on biological diversity

- Ensure that the World Heritage Convention and the Wetlands Convention give explicit attention to the contributions they can make to conservation of biological diversity in times of rapid climate (and social) change, in addition to the relevant sections of the conventions on Climate Change and Biodiversity.

- Provide additional support to international efforts at *ex situ* preservation, including the Consultative Group on International Agricultural Research; and encourage them to expand their scope to include more wild relatives of domestic plants.

- Ensure that considerations of biological diversity are given much higher profile in the intergovernmental discussions taking place on the subject of climate change, including the International Biosphere Geosphere Programme (IBGP), the Inter-Governmental Panel on Climate Change (IPCC), and World Climate Programme (WCP).

- Mobilize the biosphere reserve network coordinated by UNESCO to support research, training, monitoring, and demonstration in the area of biological diversity and climate change.

Support mitigating actions in other sectors

- Ensure that discussions of greenhouse gasses, pollution, the ozone hole, etc., also seek to mitigate the effects of climate change on natural ecosystems. Conversely, ensure that measures aimed at mitigating the effects of climate change in other sectors, such as forestry, agriculture, and coastal zone management, give full consideration to the effects of such measures on biological diversity; such mitigation measures should be subject to the preparation of full and detailed environmental impact analysis.

- Ensure that discussions aimed at conserving local cultures give full recognition to the contribution that traditional knowledge can make to larger patterns of adapting to change.

- To provide a focus to the wide diversity of approaches to conserving biological diversity, support a major international programme to conserve biological diversity (Miller, Reid, and McNeely, 1989) through research, policy reform, field action, and public awareness.

- Seek to demonstrate the wider social and economic benefits of conservation, particularly as they contribute to increasing the productivity of agriculture, agroforestry, and animal husbandry, based on the premise that adapting to climate change will involve drawing on an even wider range of genetic variation in the future than it has in the past.

CONCLUSION

The implications of anthropogenic climate change for biological diversity are profound and detailed studies are required to prescribe steps that can be taken by governments and the international community to adapt to the changes that seem almost certain to come. Such studies should build on three principles:

- First, maintaining maximum biological diversity assumes far greater urgency as the world becomes increasingly threatened by rapid climatic change. Diversity in species provides the raw materials with which different communities will adapt to these changes, and the loss of each additional species reduces the options for nature and people to respond to changing conditions.

- Second, global generalizations are unlikely to be sufficient as a basis for response to the problems. While broad patterns of climatic change can be predicted, the real impacts will be felt locally; and these impacts are unlikely to be predictable with much precision. Recommending action in the face of great uncertainty is a risky business, but it is surely sensible to provide local communities with the capacity to adapt to these changes, based (among other things) on traditional knowledge about local ecosystems and their management.

- Third, all indications are that climatic change is a continuing phenomenon which follows a number of inscrutable cycles. Considerably greater scientific attention needs to be given to studying climate change and its implications for all ecosystems terrestrial, marine, and freshwater.

The combination of maintaining the maximum possible biological diversity, the maximum possible cultural diversity, and the greatest possible scientific endeavour would seem the most sensible approach toward dealing with the dynamic future facing humanity.

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de Menocal (1995), has found that records of African climate variability obtained from deep sea drilling of marine sedentary sequences near the continent documents a shift toward more arid conditions after 2.8 million years ago, evidently resulting from remote forcing by cold north Atlantic sea-surface temperatures associated with the onset of northern hemisphere glacial cycles. African climate before 2.8 million years ago was regulated by low-latitude insolation forcing of monsoonal climate due to earth orbital precession. Major steps in the evolution of African harmonids and other vertebrates are coincident with shifts to more arid, open conditions near 2.8, 1-7, and 1.0 million years ago, suggesting that some speciation events of the Pleistocene may have been climatically mediated because the cooler and dryer African conditions at these dates may have established "discrete opportunities for ecologic fragmentation and genetic isolation leading to the eventual rise of arid-adapted species".

48. Since species in the tropics often have narrower niches than in the less species-rich temperate zones, changes in species composition may result in the extinction of local populations.

49. When CO_2 increases, seedlings in forest gaps may grow more quickly, so turnover rates in tropical forests may increase.

50. It may well be that increased fire or other disturbances that break up the canopy would increase the likelihood of invasion by alien species.

51. The most significant threat to tropical forests from climate change are associated with drying trends, changes in rainfall patterns and seasonality which in turn could lead to changes in species distribution and composition. In some sensitive areas, species may become extinct. In such a situation, tropical forest management strategies during a period of climate change should emphasize ecosystem resilience, connectivity in an increasingly fragmentary landscape, reducing fragmentation, reducing the opening of forest canopies in logging operations, and finding ways of using forest resources in an environmentally sustainable manner.

52. If all estimated conventional fossil fuel reserves are burned, the atmosphere will hold about 3-4 times as much carbon-dioxide as in pre-industrial times (Tans and Bakwin, 1995). The terrestrial biosphere, including vegetation and soils, could remove at most one-third of the carbon-dioxide emitted.

53. Regarding biotic interactions and global change, several general points have been made (Kareiva, *et al.*, 1993):

- Specific predictions cannot be made with general data.
- Models are only as good as the data used to design and execute them, and all results are restricted by assumptions.
- Species have genetic and life-history "baggage" that can ameliorate or exacerbate the effects of environmental changes.
- There is no such thing as a single effect on climate or habitat change on a species or community, as the relationships are far more complex.
- Not enough is known empirically to answer many basic conservation-related ecological questions, calling for greatly-accelerated research.

54. Pearce (1995) reports on a study that showed that dangerous levels of the pesticide toxaphene found in several fish species in Lake Laberge in the Yukon came from air pollution, possibly from as far away as the tropics. Toxaphene levels were more than 10 times Canadian health limits, putting at risk the health of rural communities who depend on such fish. The pesticide has been banned in Canada for a decade, and the study

concludes that the high concentration of toxaphene in fishes came entirely from the "biomagnification" of pesticide distilled from the air. The chemical is concentrated in the body fat of animals and accumulates at ever higher concentrations in each successive predator. Comparisons with neighbouring lakes showed that concentrations were highest in fish from lakes with the longest food chains.

55. As Webb and Bartlein (1992) have concluded, the response of species to climate change is highly individualistic.

56. Jacobson *et al*. (1987) have mapped the changes in distribution of a number of plant species in North America over the past 18,000 years, showing that different combinations of taxa form and later disassociate. From the period from 12 to 18,000 years ago, a spruce parkland was fairly common, but disappeared before spruce and birch combined to form the modern boreal forest at about 6,000 years ago.

57. Vrba (1992) has shown that the mammal exchange between North and South America over the past two and half million years depended on the interplay of orbitally and tectonically induced climate changes.

58. One of the important mechanisms in climate change is the contrast between land and sea in translating the changing seasonal intensity of insolation into stronger and weaker monsoons and thus in producing periodic large changes in moisture balance in tropical climates. Climates thus change not just in location but also in character which alter assemblages of plants and animals and lead to the emergence of new associations and ecosystems (Webb and Bartlein, 1992). Continuous changes in associations among taxa have led to continuous changes in the relationships between the species and the environmental variables, thus inducing large changes in species abundance as favourable climatic conditions appear and disappear. Thus many taxa which currently are abundant have experienced long periods when they were rare or had fragmented distributions.

59. Webb and Bartlein (1992) conclude that climate changes on all time scales, making notions concerning steady-state equilibrium and climax theory inappropriate for time scales of 200 years or longer.

60. During the Middle Ages, a run of long hot summers and short cool winters encouraged peasants to grow more crops and produce more peasants. This led to a population explosion which increased its population from 25 million in 700 to 75 million by 1250 (Nikiforuk, 1992). This population explosion was quickly followed by the Black Death, as the plague led to waves of peasant die-offs which in turn translated into acute labour shortages and ended the chronic under-employment that characterized life in the 13th century. This ultimately killed feudalism, as the value of peasant labour became significantly higher.

61. Schüle (1992) has tried to show that prehistoric human activities are likely to have sufficiently influenced the carbon, nitrogen and water flux of the biosphere (including the atmosphere) to trigger the climatic oscillations of the pleistocene. He contends that herbivores exert a greater influence on vegetation than does the climate, except under extreme climatic conditions. When certain species of herbivores became extinct or their populations were dramatically reduced, the flux of organic carbon, nitrogen, and mineral nutrients was greatly altered, as a higher percentage of the primary phyto production was temporarily stored in vegetable biomass thus slowing the flux of carbon and diminishing the amount of atmospheric CO_2.

Acid rain has made thousands of Scandinavian and North American lakes and pools virtually lifeless, and, in combination with other kinds of air pollution, has damaged forests throughout Europe (Blank, 1985; Bucher and Bucher-Wallin, 1989; Schindler, 1988).

The air is polluted mainly from combustion of fossil fuels, power plants, industry, cars, houses, ships, etc. The main pollutants are carbon dioxide (CO_2), sulfur dioxide (SO_4), nitrogen oxides

(NO_x), ammonia (NH_3), ozone (O_3), heavy metals and organic micro-pollutants. The concentration of CO_2 in the atmosphere is annually increasing by about 2.9 x 10^9 tonnes (Mooney *et al.*, 1987), and may cause a warming of the Earth through the so-called 'greenhouse effect'. The impact of increased carbon dioxide in the atmosphere is not always negative, as some plants may gain considerable benefits from such increases; but it is apparent that increases in carbon dioxide have systemic effects on plant-insect herbivore interactions (Fajer, *et al.*, 1989; Freedman, 1989). The SO_2, NO_x and O_3 released into the atmosphere may directly affect crop and vegetation including forests (Hutchinson and Meema, 1987; Bucher and Bucher-Wallin, 1989). SO_2 and NO_x oxidized and converted to strong acids are precipitated and affect terrestrial and aquatic ecosystems negatively, directly by decreasing pH and indirectly by mobilizing toxic metals, especially aluminium (Chia *et al.*, 1984; Hildrew *et al.*, 1984; Rosseland *et al.*, 1990). Heavy metals and organic micropollutants are also toxic by-products decreasing air quality. In heavily-affected areas pollution is a threat to the health of animals, humans included, by the accumulation of toxics through the food chain (Peakall, 1975; Porter *et al.*, 1984; Reutergårdh, 1988; Beryland, 1991).

The deposition of airborne pollutants on grasslands can have significant deleterious effects. In southwest Poland, one of the most highly polluted regions in Europe, Breymeyer (1990) showed that the species composition of an area of grassland significantly affected by pollution was highly impoverished, with only three species of grasses making up 75-97 percent of the plant biomass. Above-ground growth of plants was severely stunted and the soil fauna was decreased in biomass and proportion of large fauna. Particularly noteworthy was the reduction in oligochaeta which are important for decomposition. Above-ground insects were small and assimilated food less efficiently, consequently needing to consume more plant matter and providing less prey for birds and other predators.

Acid rain has numerous system effects (Eney and Petzold, 1987). On poor, acidified soils in the Netherlands, Graveland *et al.*, (1994) found that many passerine birds produce eggs with thin and porous shells, leading to high incidence of clutch desertion and empty nests. Eggshell defects were found to be caused by calcium deficiency which in turn is caused by acid deposition. Acidification has also been implicated in greatly increased mortality of moose (*Alces alces*) in Sweden by leading to trace element imbalance and specifically deficiencies in essential trace elements such as copper and chromium (Frank *et al.*, 1994).

Long range transported air pollutants are precipitated as dry deposits or as acid rain and snow with negative effects on soil (chemistry and microflora), crops and forests (e.g., Hutchinson and Meema, 1987; MacKenzie and El-Ashry, 1989; Likens, 1989).

Acid sulphur and nitrogen products precipitated from the air discharged from the catchment affect water quality and thereby aquatic vegetation and animals (Hynes, 1960; Henriksen *et al.*, 1992; Rosseland and Staurnes, 1994). Heavy metals from anthropogenic sources, industry waste waters, land deposits and mining activity are affecting the water quality and the biota. The acidified precipitation can also mobilize trace metals and enhance their bioavailability (Vesely, 1994). Eutrophication of aquatic systems due to run-off of fertilizers from agriculture, increased nitrogen run-off from acid precipitation, or of nutrients and organic matter from sewage may lead to blooms of toxic algae, oxygen deficits or even production of the highly toxic hydrogen sulphide in lake and marine sediments (Mannion, 1992; Goudie, 1993) (Box 6). Aquatic life is also threatened by organic, chlororganic and other micropollutants from polluted rain.

Chemicals added to ecosystems by human action can have profound ecosystemic effects. Peterson *et al.*, (1985), for example, report that a river in northern Canada was transformed from a heterotrophic condition to an autotrophic condition through the addition of phosphorus from air pollution. Higher nutrient input from agricultural run-off (and also from human wastes) increases the primary production of coastal waters (80-90 percent of nutrient input is taken-up by primary production in estuarine and nearshore waters -- GESAMP, 1990) and has, for example, increased primary productivity in the Baltic Sea by 30 percent (Hammer *et al.*, 1993). However, this has not been followed by an increase in decomposition and the net result has been the production of anoxic conditions in deeper waters, either impoverishing or completely eliminating benthic communities. These conditions have also substantially reduced the spawning area for cod which require a minimum salinity for successful spawning only found in the deeper waters of the Baltic.

Satellite altimeters are becoming sufficiently sophisticated to measure changes in sea level, indicating rates of sea level rise of 3.9 ± 0.8 mm per year, substantially more than had earlier been estimated (Nerem, 1995). Many species will not be able to redistribute themselves fast enough to keep up with the projected changes, and considerable alterations in ecosystem structure and function are likely. In the United States rising seas in the next century may cover the entire habitat of at least 80 species already at risk of extinction. Many of the world's islands would be completely submerged by the more extreme projections of sea level rise -- wiping out their fauna and flora, not to mention human habitations. And protected areas themselves will be placed under stress as environmental conditions deteriorate within them and suitable habitat for their species cannot be found in the disturbed land surrounding them.

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