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EXECUTIVE OVERVIEW OF WORLD WILDLIFE'S CONFERENCE ON CONSEQUENCES OF THE GREENHOUSE EFFECT FOR BIOLOGICAL DIVERSITY

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Introduction

World Wildlife Fund organized the first Conference on Consequences of the Greenhouse Effect for Biological Diversity, which was held October 4-6, 1988 at the National Zoological Park in Washington, DC. This meeting was the first to focus on how conservation of natural ecosystems would be effected by global warming. Prior to this meeting there existed no aggregated body of information about possible ecological effects, and very few scientists were doing relevant research or interpreting existing data in terms of climate change. Because effects had not been identified, biological diversity was largely overlooked in conferences and reports on global warming. Therefore, this conference had the groundbreaking role of pulling together existing information, stimulating scientists whose work could be relevant into focusing their efforts on global warming, drawing general conclusions about conservation consequences, and communicating these conclusions to the scientific, policy, funding, and management communities.

In preparing for the conference, we identified experts in a wide variety of fields, including animal and plant physiology, ecology, animal behavior, and epidemiology. Some workers were knowledgeable about specific ecosystems, including tropical forests, eastern North American deciduous forests, arctic tundra, and arctic marine systems. Others were synthesists who focused on interactions between various environmental components, such as precipitation and soil chemistry, and on synergisms between climate change and other human activities, such as deforestation. Steve Schneider of the National Center for Atmospheric Research provided the scientists with a generic global warming scenario, based on computer models of future climate, and we challenged the scientists to respond to this scenario by projecting how their particular ecological systems would be likely to respond. In some cases their projections were based on ecological computer models that were tightly linked to the climate projections, while in other cases the projections were based upon deduction and knowledge of how ecological systems have responded to past climate changes. We not only asked each specialist to identify what is currently known about how their system would respond, but also what is not known. Thus, the conference acted not only to pull together current knowledge, but also to identify gaps and suggest future research.

The conference was resoundingly successful. It was attended by 350 people, primarily scientists, representatives of government agencies, funders, and the press. Press coverage was extensive: multipage reports of the conference were carried by newspapers and the major general science journals and conservation magazines, including Science, Bioscience, New Scientist, Trends in Ecology and Evolution, Defenders of Wildlife, Greenpeace, Sierra, and National Parks and Conservation. We thus achieved our primary goal which was to ensure that discussion of global warming's effects and policy responses should include consideration of biological diversity.

General Conclusions about Biodiversity

The most general conclusion to be drawn from the conference is that many ecological systems will be dramatically changed by warming. Among the projections are that the ranges of species will shift large distances, 100's of kilometers toward the north in the north temperate zone, ecological communities will break up and reassort, and many species extinctions are likely, given that for some species climate will become unsuitable in much or all of their present ranges. In some cases, entire food webs may be disturbed, as projected by Vera Alexander for the Arctic marine ecosystem.

Unfortunately for accurate prediction, the nature of these effects is extremely complicated and poorly understood. To begin with there are many uncertainties surrounding the climate projections. Although a variety of climate models concur in projecting that global average temperature will rise by 3-4 °C or more during the next century, there is poor resolution at the regional level, let alone at the local level where reserve managers must act. Projections for precipitation changes associated with warming are even poorer. In most cases it is unknown at the regional level whether precipitation will increase or decrease -- provisional projections have been made at the continental level, suggesting for example that continental interiors, notably in North America, may become significantly dryer. To the uncertainty of these must be added effects on and interactions between soil, water, and atmospheric chemistry, sea level rise, and storm and fire frequencies. Synergistic effects with other human-caused disturbances, including acid rain and other pervasive pollutants, stratospheric ozone depletion, and habitat destruction, must all be accounted for in anticipating the future state of biological diversity. Added to these physical changes must be counted the indirect effects of changes in the biota caused by warming, including the migration into protected areas of new pathogens, competitors, and predators, including those introduced by people.

Specific Projections

Before turning to management implications, I will present some of the specific conclusions presented by scientists at the conference.

As mentioned, Steven Schneider (National Center for Atmospheric Research) provided a generic climate scenario that gave best estimates for important climate variables, including temperature, precipitation, evapotranspiration, soil moisture, and sea level rise. These estimates were derived by drawing generalizations from several General Circulation Models (GCM's). In the generic scenario it was projected that by roughly the middle of the next century global annual temperature would have increased between 2 and 5 °C. Precipitation was projected to increase globally between 7 and 15 percent, although there will be substantial regional variation. Sea level rise was estimated at between 10 and 100 centimeters. Temperature rise could cause a net increase in evapotranspiration of between 5 and 10 percent. In the above cases regional projections are possible, and the regional projections range in confidence from "medium" for temperature and sea level rise to "low" for precipitation and evapotranspiration.

These estimates are based on a study done for the American Association for the Advancement of Science and are conservative.

They reflect the consensus view of climatologists that the best estimates for warming are 3 +/- 1.5 °C, as concluded by the National Academy of Sciences (NRC, 1983) and the World Meteorological Organization (1982). Some recent estimates of future warming have tended to push the range upward, including an estimate by Schlesinger (1989) of 4.2 +/- 1.2 °C or even a possible 8 to 10 °C (Lashof, 1988).

Two points with important conservation implications were stressed by Schneider. First, the rate will be very fast compared with past normal warmings, perhaps 50 times as fast. Second, along with heating will come changes -- often increases -- in the frequency of extreme events such as fires, hurricanes, and droughts. As described in more detail below, extreme events may be more important than temperature change per se in changing patterns of biological diversity.

All changes will have profound if inexactly known effects on natural ecosystems. Some of the more precise projections, based upon specific GCM's, were made for changes in North American temperate forests. Margaret Davis and Catherine Zabinski (University of Minnesota) presented future range maps for four important eastern trees, sugar maple, beech, yellow birch, and hemlock. They predicted that in response to 3°C of global warming these species would die out in the southern parts of their ranges, withdrawing hundreds or a thousand kilometers or more toward Canada. Die-offs of these and other forest species that share the same ecological requirements would substantially change the eastern temperate deciduous forest. Some of the species associated with these trees, particularly understory plants, may be even more susceptible to warming effects than the dominant trees (Davis and Zabinski). Reserves situated in this area would be likely to lose many of the species within them.

In addition to latitudinal changes in species ranges, there will also be upward shifting on mountains in response to die-offs at low elevations coupled with upward colonization. Because mountain tops are smaller than bottoms, a species shifting upward will generally have a smaller range. Dennis Murphy and Stuart Weiss (Stanford University) focused their attention on butterfly and mammal populations in mountain ranges of the U.S Great Basin, projecting that, based on species area relationships, many local extinctions would occur as ranges decreased, leading to an estimated 23% loss of butterfly species per mountain range. Not surprisingly, sedentary species would be hardest hit, with a 30% loss. Mammals were projected to lose approximately 44% of species. For both groups, small mountain ranges would lose more species than large ones.

Daniel Botkin and Robert Nisbet (University of California at Santa Barbara) complemented the work of Davis and Zabinski by modelling changes in species composition occurring as climate warms within specific sites of temperate eastern forest. They presented projections that a site in the Boundary Waters Canoe Area of Minnesota would change over from the present balsam fir-dominated softwood forest to an eastern hardwood forest within as little as 30 to 50 years. The Grayling, Michigan jackpine, which is essential habitat for the endangered Kirtland's warbler, was projected to die-out and be replaced by a sugar maple-dominated forest also within approximately the same time period.

Of course species will not all remain in place to die as climate changes. Those, like birds, that are efficient dispersers, can respond to shifting climate zones by colonizing areas where the climate becomes suitable. A species' ability to track shifting climate depends upon both its intrinsic dispersal ability -- whether it is a highly mobile disperser -- and upon whether there are barriers to dispersal in the way. Robert Peters (World Wildlife Fund) pointed out that even under natural rates of climate change, barriers like mountains have caused extinctions by preventing species from following shifting climate. In the next century, it is likely that most species will be isolated in habitat islands surrounded by roads, cities, and fields, and shifting will be difficult. Norman Myers reemphasized this point, pointing out that interaction between habitat destruction and climate change is synergistic, in that combined they threaten more species than the sum of their individual effects.

If the rate of climate change is so fast that the preferred climate "runs away" toward the north faster than a species can follow, extinction is possible even if no barriers to dispersal exist. Davis and Zabinski provided estimates of average migration rates for North American trees, on the order of 20-40 km per century, which are too low by an order of magnitude to track shifting climate. In the projected warming, with warming rates as much as 50 times higher than normal, it is likely that many such species will not be able to reach sanctuaries.

Because different species have different dispersal abilities and respond differentially to various ecological forces, communities tend to fragment as species shift their ranges in different directions. Both Thompson Webb (Brown University) and Russell Graham (Illinois State Museum) presented extensive evidence showing such breakup and reassortment of plant and animals associations during past climate changes. For instance, Webb described how 18,000 years ago spruce and sedges grew together in open woodland associations, but that by 10,000 years ago the spruce forest closed and sedges were no longer associated with spruce. Such differential shifting means that climate change will indirectly stress species by forcing them to cope with new assortments of predators, competitors, and diseases.

Changes in the distribution of pests, disease vectors, and diseases will affect natural resources, species of conservation concern, and human health. The forest industry, for example, is concerned about possible range expansion of pests destructive to valuable timber trees (Winget, 1988). Andrew Dobson (University of Rochester), an epidemiologist, focused on the African tsetse fly, carrier of sleeping sickness. Areas in which sleeping sickness is prevalent cannot be used for cattle production and are therefore de facto wildlife refuges. Dobson projected that warming would cause a substantial shifting of the sleeping sickness belt, opening wildlife areas to human settlement, while at the same time making new areas unsuitable for cattle. He further projected that the U.S. could expect a northward expansion of important tropical disease vectors not now major problems, including the malarial mosquito. Peters pointed out that dispersal rates for pests and diseases tend to be very high, often over 100 kilometers per year, while rates for other species may be much slower, such as the 40 or so kilometers per century that can be covered by tree dispersal. This means that rare species within reserves, while unable to track shifting climate themselves, may nonetheless be easily found by threatening diseases and pests.

Because warming will be much greater at high latitudes than nearer the Equator, arctic ecosystems will experience even greater warming and ecological change than the temperate ecosystems described above. Several speakers described dramatic changes in tundra systems: Ian Woodward (University of Cambridge) suggested that tundra vegetation could be pushed as much as 4 degrees of latitude toward the North. This echoes projections made elsewhere (Emanuel, Shugart, and Stevenson, 1985) that as much as 32% of tundra vegetation could be replaced by forest if climate warms an average of 3°C. Dwight Billings and K. Peterson (Duke University) focused on coastal wet tundra and suggested that warming would cause melting of permafrost with subsequent thermokarst erosion and loss of peat and sediments. Vera Alexander (University of Alaska) described the critical importance of continued sea ice to the arctic marine food web. Without sea ice, which would disappear from much of the arctic ocean under some warming scenarios, marine mammals lack ice-flows on which to rest, travel, and pup, and the effective growing season for phytoplankton, upon which the entire food chain depends, would be significantly shortened. The result could be collapse of large marine mammal populations.

One group of animals that depend upon tundra and thus could be at risk are migratory shorebirds. Pete Myers (National Audubon Society) described the potential plight of shorebirds which need to synchronize their migrations with the timing of food availability. If, for example, they arrive in the arctic at their usual time, but insect abundance has peaked early because of unusually warm weather, there may be inadequate food to raise young to fledging. This illustrates the general case that migratory animals throughout the world will be at risk because of the need for precise synchrony of movement and resources, a synchrony which often has some components mediated by climate.

In the tropics, temperature rise itself is expected to be relatively small, but Gary Hartshorn (World Wildlife Fund) stressed that the projected changes in rainfall patterns could cause substantial disturbance in tropical forests. Timing of fruiting and flowering are determined in large measure by the temporal distribution of droughts and rainy periods, and if these change, ecosystem effects can be severe. Hartshorn provided case studies for Barro Colorado Island in Panama and La Selva Biological Station in Costa Rica. On Barro Colorado, when rain continued during what should have been the normal dry season, normal flowering and fruiting failed and there was mass starvation and emigration among fruit-eating birds and mammals. On the other hand, unusual lack of rain can also have severe consequences, including deaths of adult trees. Another major source of disturbance in some tropical forests is hurricanes, which are projected to increase in frequency with warming. Massive blowdowns caused by hurricanes can change local ecologies substantially, decreasing wildlife populations by habitat destruction and direct mortality. The endangered Puerto Rican parrot, for example, experienced large population crashes leading to local extinctions during major hurricanes in 1928 and 1932 (Snyder, Wiley, and Kepler, 1987).

Disturbance regimes in general play major roles in determining suitability of habitat for species, and will play major roles in facilitating turnover of one species or vegetation type to another in response to climate change. Jerry Franklin (University of Washington) pointed out that adult coniferous trees in northwestern U.S. forests are relatively resilient to climate change, and that the forest collectively ameliorates local climate. The result is that even given substantial warming, in the absence of major disturbance, the forest would be able to survive in the long-term, at least until the mature trees die of old age. However, Franklin stresses that turnover would actually be fairly rapid given an increased frequency of fires caused by hotter, dryer conditions. The same would be true of forest loss due to blowdowns or cutting. When the old forest is removed, in many areas conditions would not be suitable for its reestablishment. Walter Westman (University of California) made the same point for California chaparral, that increased disturbance by fire would play a major role in the turnover of vegetation types. Given the recent extensive burning in Yellowstone, fire and subsequent replacement of trees by different species mixes should be flagged as a major concern for managers.

Sea level rise is one aspect of global change about which climatologists are relatively knowledgeable on even a local scale -- at least they know that the direction of change is likely to be positive, with estimates in Schneider's scenario of 10 to 100 centimeters rise. Several authors, including Peterson Myers, Larry Harris (University of Florida) and Carleton Ray and coauthors (University of Virginia) described loses of coastal wetlands as a major concern. (The EPA has projected losses in the U.S. of between 40% and 73% of all existing coastal marsh in response to a 3 °C rise in global average temperature under low and high sea level rise scenarios, respectively). Harris described effects on south Florida ecosystems, including "loss of the Everglades" due to extensive salt water intrusion, which would threaten the endangered Florida panther and Everglades kite.

Conservation Implications

The scale of possible disruption to natural ecosystems makes it a top priority to slow or stop production of greenhouse gases. This will be difficult, not only because fossil fuel use and other sources of greenhouse gases are likely to increase as the world's population grows, but also because effective action will demand a high degree of international cooperation. Unfortunately, climatologists project that even were all gas production stopped immediately, gas concentrations already in the atmosphere are sufficient for ecologically significant warming.

If global temperatures continue to rise, then ameliorating the negative effects of climatic change on biological resources will require substantially increased investment in reserve purchase and management.

To make intelligent plans for siting and managing reserves, we must refine our ability to predict future conditions within them. Vital information includes data on how temperature, precipitation, CO_2 concentrations, and interspecific interactions determine range limits (e.g., Picton 1984; Randall 1982) and how they can cause local extinctions. Adequately understanding the influences of climate on population dynamics may require long-term studies of reserve populations, studies similar to Ehrlich's two decades of research on checkerspot butterflies (Ehrlich 1965; Ehrlich et al. 1980).

In addition to basic research, reserves that suffer from the stresses of altered climatic regimes will require carefully planned and increasingly intensive management to minimize species loss. For example, modifying conditions within reserves may be necessary to preserve some species; depending on new moisture patterns, irrigation or drainage may be needed. Because of changes in interspecific interactions, competitors and predators may need to be controlled and invading species weeded out. The goal would be to prevent loss of existing species by forestalling both succession and habitat deterioration, much as the habitat of Kirtland's warbler is periodically burned to maintain pine woods (Leopold 1978).

If such measures are unsuccessful, and old reserves do not retain necessary thermal, moisture, or other characteristics, individuals of disappearing species may have to be transferred to new reserves. For example, cold-adapted ecotypes or subspecies may have to be transplanted to reserves nearer the poles. Other species may have to reintroduced in reserves where they have become temporarily extinct. An unusually severe drought, for example, might cause local extinctions in areas where a species ordinarily could survive with minimal management. Such transplantations and reintroductions, particularly involving complexes of species, will often be difficult, but some applicable technologies are being developed (Botkin, 1977; Lovejoy, 1985).

To the extent that we can still establish reserves, pertinent information about changing climate and subsequent ecological response should be used in deciding how to design and locate them to minimize the effects of changing temperature and moisture. In many areas of the Northern Hemisphere, for example, where northward shifts in climatic zones are likely, it makes sense to locate reserves as near the northern limit of a species' range as possible, rather than farther south, where conditions are likely to become unsuitable. We can also deduce that reserves located near the southern limits of species ranges may have the greatest risk of losing species.

It is often suggested that reserves might best be placed in areas of high species endemism, like the presumed Pleistocene refugia of South America, which are often interpreted as areas where many species successfully survived and diversified during past periods of drying (Terborgh and Winter 1983). Siting reserves in such areas maximizes the number of endemic species saved in each reserve. A similar good argument for cost-effectiveness can be made for areas of high species diversity. In either case, knowing the long-term effects of future local climate would be invaluable in determining whether a species or endemic-rich reserve is indeed suitable for the long-term survival of the species within.

Locating reserves where topography and soil types are heterogeneous could increase the chance that a species' precise temperature or moisture requirements would be met. Wilcox and Murphy (1985) have shown that populations of a checkerspot butterfly survive longer under normal climatic fluctuations if they inhabit several slopes that face different directions and thus have different moisture characteristics. Altitudinal variability within a reserve would increase the chance that vertical shifting could occur. Fortunately, many reserves have been placed in mountainous land because such areas are generally less suitable for agriculture.

Maximizing the size and number of reserves would enhance the long-term survival of species. In large reserves, species would have a greater chance of finding suitable microclimates or of shifting altitudinally or latitudinally. If we could increase the number of reserves so that each species and community type were represented in more than one reserve, we would increase the chance that if the climate in a reserve became unsuitable, the organisms within it might still survive elsewhere.

Flexible zoning around reserves could preserve an option to shift reserve boundaries in the future, as, for example, by trading pasture land for reserve land. The multiuse, multizoned biosphere reserves now being set up in some countries, such as India (Saharia,1986), provide models of the sort of flexibility needed.

The unique situation of each reserve will challenge managers and planners to produce further ideas for maintaining biological diversity, and their task will be made more difficult by how fast changes are likely to occur. If we wait until we can predict exactly which parts of the world will be wetter or drier, for example, it will be too late--too late to begin the time-consuming task of setting up alternative reserves, too late to begin studying the effects of climate on competitive interactions, too late to identify those species most vulnerable to climatic change.

First Steps for Reserve Systems

What concrete steps should be taken now by agencies and organizations responsible for the management of reserves and natural resources? How can they act to preserve species that may soon be dying out over large portions of their ranges?

As described above, nature reserves are likely to experience climate change sufficient to substantially change current ecological conditions within them. Some species inside a reserve will die out or become rare, some will become more common, and new species, primarily those that have efficient dispersal mechanisms, will invade. If climatologists' projections are correct, these changes will provide the greatest challenge ever to the integrity of reserve systems.

From the reserve manager's point of view, the changes will present many difficult practical and philosophical questions. Should the manager strive to preserve all the species within the park, given that climate change is causing some to disappear? Should management be used to conserve examples of community types, given that, on the time-scale of climate change, communities are temporary assemblages of species likely to break up as the earth warms? How should the recent evolution of a "let nature take its course" management philosophy, as has been practiced by the National Park Service in Yellowstone, be reconciled with the increasingly intensive management that will be necessary to conserve many species in a warming world? Response to this problem will be difficult because, although the changes will be rapid from an ecological point of view, they will be slow in relation to management's traditionally short-term planning horizon. Thus, to ensure rapid response, continuity, and adequate resources, it will be necessary for high level authority within management agencies to give this issue high priority. Without such high level initiative, it is unlikely that substantial, sustained resources will be allocated to a problem with a 20 to 60 year time horizon when so many immediate problems threaten.

In addition to focusing on changes within protected areas per se, there is the larger concern over potential losses of biological diversity on a regional or global scale. Even more than now, parks and other reserved lands will have to be part of carefully integrated conservation plans on the regional or global scale. For example, as climate changes, some northern parks might be targeted as introduction sites for species from the southern regions of the country where conditions no longer permit their survival. The current efforts to provide a basin-wide conservation plan for the grizzly bear in the Greater Yellowstone

Area might provide a model for regional planning.

A major difficulty facing the reserve manager is uncertainty. Reliable local climate projections will probably not be available in the near future. Temperature, rainfall, changes in growing seasons, frequency of extreme events like fires and storms, and secondary effects on soils and waters can be guessed at but will not be known with the degree of certainty that managers are used to for dealing with, for example, projections of visitor growth. At the next level, i.e. that of biotic interactions driven by climate, the complicated interplay of predators, competitors, and diseases will be extremely difficult to forecast. Nonetheless, even given these uncertainties, some general guidelines are possible, and there are specific activities that can be useful. Contingency plans can be made, information can be gathered, and expertise developed in critical skills like restoration ecology. The following suggestions for response have been developed from discussions stimulated by the October conference.

1) Monitoring. One of the most important steps is to institute long-term monitoring of local climate changes and the dynamics of species and communities. Baseline information is necessary to identify the beginning of warming effects, to distinguish short-term from long-term changes, to help identify susceptible species and communities, to identify the nature of potential

changes, such as the direction of climate-driven plant succession, and to provide the basis for identifying the relationships between changes in climatic variables and resultant change in the biota. Changes might be expected to show up first at high latitudes, in low-lying marine coastal environments, and generally at ecotones between vegetation types determined by both temperature and precipitation. Change-over from one vegetation type to another might first be identified where disturbance events create succession.

Monitoring for climate change may be done at different locations than other sorts of ongoing monitoring. For example, transects in Merritt Island National Wildlife Refuge in Florida for studying effects of burning on vegetation are typically laid out in the center of a plant community, while a climate transect should more likely be at the interface between two communities.

2) Ecological Research. Monitoring should be backed up by specific experiments on species and community responses to climate variables. Autecological studies can demonstrate which species have their ranges within a reserve determined by climate. Species of particular interest, such as endangered species, could receive special attention as to the effect of climate on, for example, food supply. Studies on climate-mediated competition would be valuable. Paleoecological studies and dendrochronology can shed additional light on past climate change and biotic

response within reserves.

3) Identify Sensitive Communities, Species, and Populations. The results of monitoring, research, and analysis based on present information should allow identification of species or communities of special concern. Such might include species that are nationally or globally rare or endangered, or which have peripheral populations within a reserve that are therefore likely to be stressed by relatively small amounts of early transitional warming. Sensitive species would be targeted for additional monitoring, research, and the development of management techniques.

4) Development of contingency plans. Long-term plans for protected areas should have provisions for climate change, with monitoring and research, as described above, a particularly important component because they provide warning and understanding of approaching problems. Even though precise local or regional climate projections are not available, contingency plans could be developed, particularly for sensitive biota. For example, contingency plans could be made based upon assumptions of local average warmings of 2,4,6, and 8 o^{C}; or upon assumptions of various rainfall increases and decreases. Given that in many areas increased temperature will add to water stress, it would be reasonable to make long-term plans for dealing with lower water availability. This might include plans for mitigating

effects on sensitive species, or political or legal maneuvers to ensure that the natural resources of reserves receive adequate water in the face of future competition from non-reserve uses like agriculture and development.

Because of warming's global nature, parks and other management units will increasingly be forced to become partners in planning and management that transcends the park scale. For example, as the location and abundance of habitat and critical resources changes with climate, management of specific wildlife species will increasingly need to transcend a single protected area. There is precedence: management of endangered species is already done as outlined in multi-agency, multi-institution Endangered Species Recovery Plans. The recovery activities of migratory species like whooping cranes typically span many protected areas, states, and even nations.

5) Development of Philosophical Approaches to Management. Land and wildlife management agencies should begin the process of deciding philosophical questions that will affect management. Given the likelihood of community breakups, should efforts be expended on maintaining existing communities types? As conditions become unsuitable for species existing within reserves today, should herculean efforts be expended to maintain them? Should northern reserves be used as transplantation sites for southern species in need of new habitat? At what point should

efforts to maintain a particular species within a reserve be stopped and resources used elsewhere? How can reserves become integrated components of regional, national, and global strategies for conservation of species? Given stresses on the natural world, will the role of multi-purpose reserves, like the national parks and wildlife refuges, increase relative to their recreation role?

6) Development of Management Techniques. The increased disturbance and number of threatened species likely to result from climate change demand a large increase in resources for the development and implementation of new management techniques. Many of these will fall under the heading of restoration ecology, which is the restoration of damaged ecosystems. Given changing climate, much of the restoration will take the form of transplantation or reestablishment of biota in regions where the climate becomes newly suitable. Restoration and transplantation techniques are poorly developed at present and require extensive investment in research.

As mentioned above, increased management may take the form of controlling undesirable species whose members swell or whose negative effects intensify as climate changes. Necessary techniques will be determined by climate effects on sensitive species.

7) Dedication of Additional Reserve Lands. Global warming is a strong argument for the enlargement or creation of additional parks and other reserved lands. As mentioned above, multiple refuges provide additional chances that some protected habitat will remain suitable for a particular species as climate changes. Moreover, as reserves become unable to provide adequate habitat and other resources for the species within, given climate change, enlargement may be necessary, as was done when Redwoods National Park was expanded during the 1970's to prevent external logging from threatening the park's ecosystems.

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