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In this Issue:

Effects of Global Warming on Species and Habitats
An Overview

by Robert L. Peters

Our understanding of how atmospheric composition affects global climate is still in its infancy, but an increasing body of knowledge suggests that rising concentrations of carbon dioxide and other anthropogenic polyatomic gases will raise global average temperatures substantially (National Research Council, 1983; Schneider and Londer, 1984; World Meterological Organization, 1982). Associated with this warming would be changes in a number of other chemical and physical variables, including precipitation, evaporation rates, sea level, and soil and water chemistry.

We can infer how the biota might respond to such changes by observing present and past distributions of plants and animals, which are heavily determined by temperature and moisture patterns. Thus, one race of the dwarf birch (*Betula nana*) can only grow where the temperature never exceeds 22 degrees celsius (Ford 1982), suggesting that it would disappear from those areas where global warming causes temperatures to exceed 22 degrees celcius. Recent historical observations of range changes, as detailed below for European birds, can also suggest future responses. Insight into long-term responses to large climatic changes can be gleaned from studies of fossil distributions of, particularly, pollen (Davis, 1983) and small mammals (Graham, 1986).

Such observations tell us that plants and animals are very sensitive to climate. Their ranges move when the climate patterns change — species die out in areas where they were once found and colonize new areas where the climate becomes newly suitable. We also know from the fossil record that some species have become completely extinct because they were unable to colonize suitable habitat when climate change made their previous ranges uninhabitable.

If warming occurs as projected, during the next 50 years it is likely to change the ranges of many species, disrupt natural communities, and contribute to the extinction of species.

As discussed below, there will be many ways in which climate change will stress and change natural ecosystems. If warming occurs as projected, during the next 50 years it is likely to change the ranges of many species, disrupt natural communities, and contribute to the extinction of species.

Although this paper will focus on the terrestrial biota, ocean systems may show similar shifts in species ranges and community compositions if there is warming of ocean water or alteration in the patterns of water circulation. For example, recent El Nino events demonstrate the vulnerability of primary productivity and species abundances to changes in ocean currents and local temperatures (e.g. Duffy, 1983; Glynn, 1984).

The Nature of the Ecologically Significant Changes

There is widespread consensus that global warming will occur during the next century, and that a global warming of three degrees celsius may be reached during the next 50 years (Hansen et al. 1981; NRC, 1983; Schneider and Londer, 1984). Ecologically significant temperature rise would occur during the transitional warming phase, well before three degrees celsius is reached — as discussed below, warming of less than one degree celsius may have substantial ecological effects.

For the purpose of discussion in this paper, I will take average global warming to be three degrees celsius, but it must be recognized that additional warming well beyond three degrees celsius may be reached during the next century if the production of anthropogenic greenhouse gases continues.

The threats to natural systems are serious for the following reasons. First, three degrees celsius of warming would present natural systems with a warmer world than has been experienced in the past 100,000 years (Schneider and Londer, 1984). This warming would not only be large compared to recent natural fluctuations, but it would be very fast, perhaps an order of magnitude faster than past natural changes. For reasons discussed below, such a rate of change may exceed the ability of many species to adapt. Moreover, human encroachment and habitat destruction will make wild populations small and vulnerable to local climate changes.

Second, ecological stress would not be caused by temperature rise alone. Changes in global temperature patterns would trigger widespread alterations in rainfall patterns (Hansen et al. 1981; Kellogg and Schware, 1981; Manabe et al. 1981; Wigley et al. 1980), and we know that for many species precipitation is a more important determinant of survival than temperature *per se*. Some regions would see dramatic increases in rainfall, and others would lose their

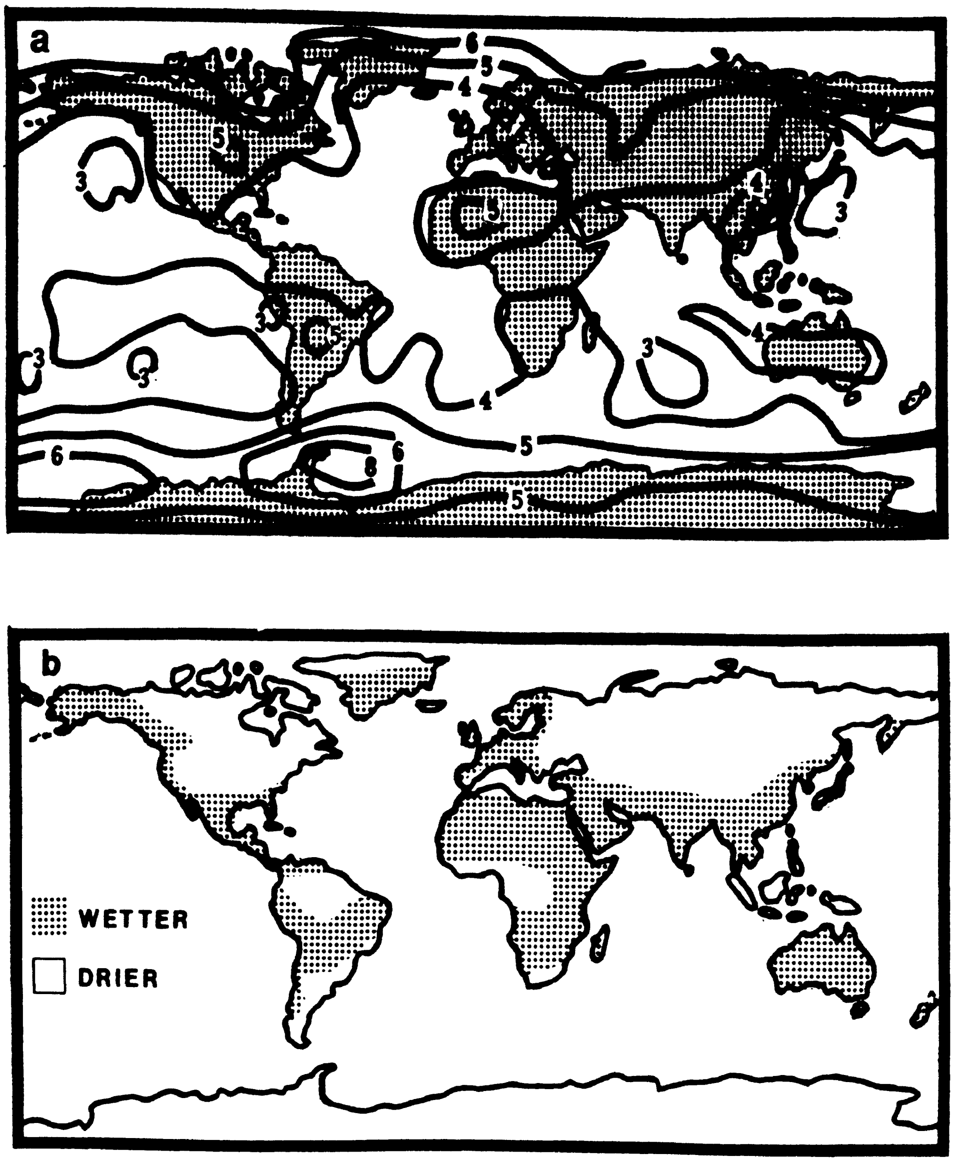

Figure 1.

(a) Global patterns of surface temperature increase, as projected by the Goddard Institute for Space studies (GISS) model(Hansen et al. 1987) in degrees C. (b) Global changes in moisture patterns (Kellogg and Schware 1981).

present vegetation because of drought. For example, Kellogg and Schware (1981), drawing on knowledge of past vegetation patterns, project substantial decreases in rainfall in America's Great Plains — perhaps as much as 40% by the early decades of the next century (Fig. 1b).

Other environmental factors would change due to global warming: Soil chemistry would change (Kellison and Weir, 1986). Increased carbon dioxide concentrations may accelerate the growth of some plants at the expense of others (NRC 1983; Strain and Bazzaz, 1983), possibly destabilizing natural ecosystems. And rises in sea-level may inundate coastal biological communities (NRC, 1983; Hansen et al. 1981; Hoffman, Keyes, and Titus, 1983; Titus et al. 1985). This means is that the ranges of individual species would shift and that ecological systems would be disrupted.

One important pattern of global warming, generally concluded by a variety of computer projections, is that warming will be relatively greater at higher latitudes. See, for example, Figure 1a (Hansen et al. 1987). This sug-

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Cover:

bay checkerspot butterfly
(Euphydryas editha bayensis)
Federally listed as a Threatened species on September 20, 1987

Photo by Paul Ehrlich

gests that, although tropical systems may be more diverse and are currently under great threat because of habitat destruction, temperate zone and arctic species may ultimately be in greater jeopardy from climate change. Arctic vegetation would experience widespread changes (Edlund, 1987). Also, a recent attempt to map climate-induced changes in world biotic communities projects that high altitude communities would be particularly stressed (Emanuel et al. 1985). Boreal forest, for example, was projected to decrease by 37% in response to warming of three degrees celsius.

A final point, important in understanding species response to climate change, is that weather is extremely variable, and extreme events, like droughts, floods, blizzards, and hot or cold spells may have more effect on species distribution than average climate *per se* (e.g. Knopf and Sedgwick, 1987).

How Do Species Respond to Warming?

We know that when temperature and rainfall patterns change, species ranges change. Even very small temperature changes of less than one degree within this century have been observed to cause substantial range changes. For example, the white admiral butterfly (*Ladoga camilla*) and the comma butterfly (*Polygonia c-album*) greatly expanded their ranges in the British Isles during the past century as the climate warmed approximately 0.5 degrees celsius (see in Ford, 1982). At the same time, other species that depend upon cooler conditions, like the ant (*Formica lugubris*), retracted their ranges into the cooler uplands.

Williamson (1975), for British and European birds, chronicles extensive and rapid range expansions and contractions in response to the warming trend during the first half of this century. In general, there has been a retreat by boreal species and expansion by temperate ones. In addition to direct climate effects, competition is implicated in a number of cases, including the replacement of the boreal brambling (*Fringilla montifringilla* with the chaffinch (*F. coelebs*) in an estimated 45% of its range in Finland and the displacement of the Siberian jay (*Perisoreus infaustus*) by the southern jay (*Garrulus glandarius*) from the Baltic states of the USSR. In some cases, hybridization has occurred rather than displacement as two previously separated species came into contact (Williamson (1975).

On a larger ecological and temporal scale, entire vegetation types have shifted in response to past temperature changes no larger than those that may occur during the next 100 years or less (Baker 1983; Bernabo and Webb, 1977; Butzer, 1980; Flohn, 1979; Muller, 1979; Van Devender and Spaulding, 1979). Such shifts show general patterns. As the Earth warms, species tend to shift to higher latitudes and altitudes. From a simplified point of view, rising temperatures have caused species to colonize new habitats toward the poles, often while their ranges contracted away from the equator as conditions there became unsuitable.

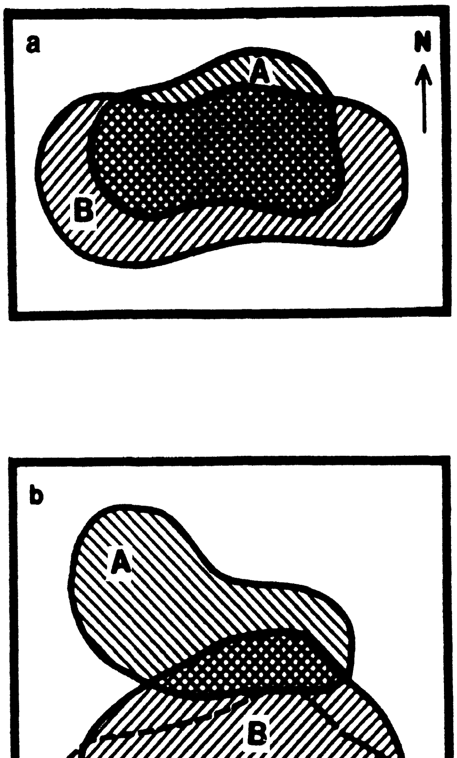

Figure 2.

(a) Initial distribution of two species, A and B, whose ranges largely overlap. (b) In response to climate change, latitudinal shifting occurs at species-specific rates, and the ranges disassociate

During several Pleistocene interglacials, for example, the temperature in North America was apparently two degrees celsius to three degrees celsius higher than now. Osage oranges and pawpaws grew near Toronto, several hundred kilometers north of their present distribution; manatees swam in New Jersey; tapirs and peccaries foraged in North Carolina (Dorf, 1976). Other significant changes in species ranges have been caused by altered precipitation accompanying past global warming, including expansion of prairie in the American Midwest during a global warming episode approximately 7,000 years ago (Bernabo and Webb, 1977).

It should not be imagined, however, that because species tend to shift in the same general direction, that existing biological communities move in synchrony. Conversely, because species shift at different rates in response to climate change, communities often dissassociate into their component species (Figure 2). Recent studies of fossil packrat (*Neotoma* spp.) middens in the southwestern United States show that during the wetter, moderate climate of 22,000-12,000 years ago, there was not a concerted shift of communities. Instead, species responded individually to climatic change, forming stable, but by present-day standards, unusual assemblages of plants and animals (Van Devender and Spaulding, 1979). In eastern North America, too, post-glacial communities were often ephemeral associations of species, changing as individual ranges changed (Davis, 1983; Graham, 1986).

A final aspect of species response is that species may shift altitudinally as well as latitudinally. When climate warms, species shift upward. Generally, a short climb in altitude corre-

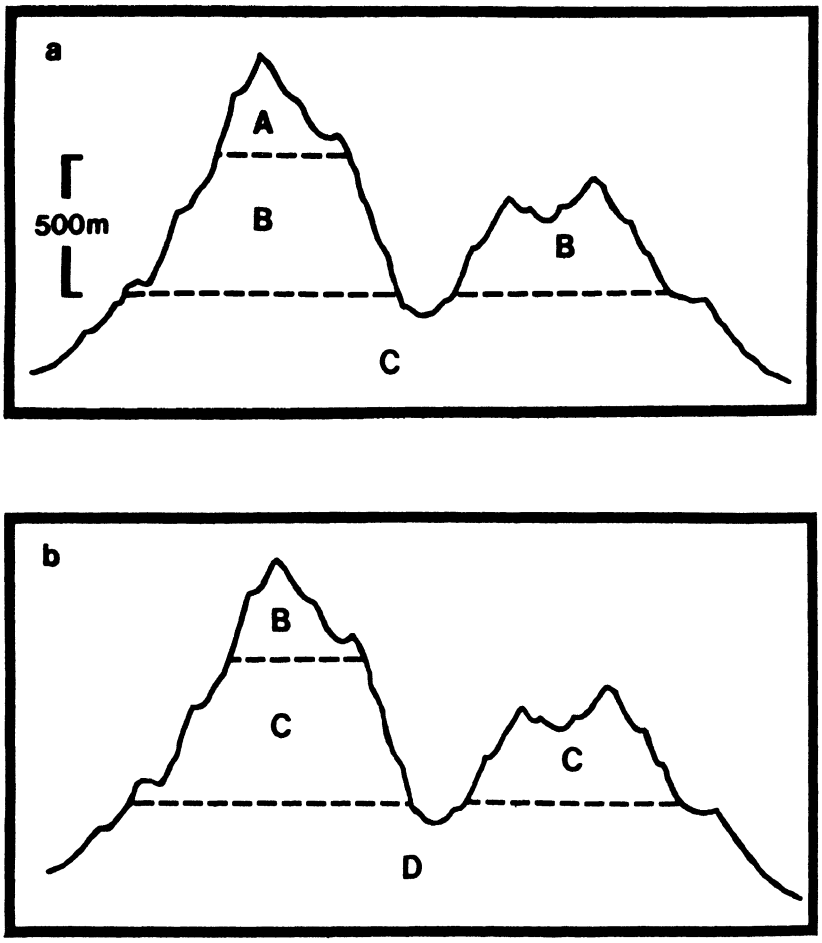

Figure 3.
(a) Initial altitudinal distribution of three species, A, B, C. (b) Species distribution after a 500m shift in altitude in response to a 3 degrees C. rise in temperature (based on Hopkin's bioclimatic law; MacArthur 1972). Species A becomes locally extinct. Species B shifts upward, and the total area it occupies decreases. Species C becomes fragmented and restricted to a smaller area, while species D successfully colonizes the lowest altitude habitats.

sponds to a major shift in latitude: the three degrees celsius cooling of 500 meters in elevation equals roughly 250 kilometers in latitude (MacArthur, 1972). Thus, during the middle Holocene, when temperatures in eastern North America were two degrees celsius warmer than at present, hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*) were found 350 meters higher on mountains than they are today (Davis, 1983).

Because mountain peaks are smaller than bases, as species shift upward in response to warming, they typically occupy smaller and smaller areas, have smaller populations, and may thus become more vulnerable to genetic and environmental pressures. Species originally situated near mountaintops might have no habitat to move up to and may be entirely replaced by the relatively thermophilous species moving up from below (Figure 3). Examples of past extinctions attributed to upward shifting include alpine plants once living on mountains in Central and South America, where vegetation zones have shifted upward by 1000-1500 m since the last glacial maximum (Flenley 1979; Heusser 1974).

Magnitude of Projected Latitudinal Shifts

Although Pleistocene and past Holocene warming periods were probably not due to elevated carbon dioxide levels, researchers have predicted that, if the proposed carbon dioxide-induced warming occurs, similar species shifts would also occur, and vegetation belts would move hundreds of kilometers toward the poles (Frye, 1983; Peters and Darling, 1985). 300 kilometers of shifting in the temperate zone is a reasonable estimate for a three degrees celsius warming, based on the positions of vegetation zones during analogous warming periods in the past (Dorf, 1976; Furley et al. 1983).

Additional confirmation that shifts of this magnitude may occur comes from attempts to project future range shifts for some species by looking at their ecological requirements. For example, the forest industry is concerned about the future of commercially valuable North American species, like the loblolly pine (*Pinus taeda L.*). This species is limited to the south of its range by moisture stress on seedlings. Based on these physiological requirements for temperature and moisture, Miller, Dougherty and Switzer (1987) projected a range retraction to the North of approximately 350 kilometers in response to a global warming of three degrees celsius.

Dispersal Rates and Barriers

The ability of species to adapt to changing conditions will to large extent depend upon their ability to track shifting climatic optima by dispersing colonists. In the case of warming, a North American species, for example, would most likely need to establish colonists to the north. Survival of plants and animals would therefore depend either upon long-distance dispersal of colonists, such as seeds or migrating animals, or upon rapid iterative colonization of nearby habitat until long-distance shifting is accomplished. If a species' intrinsic dispersal rate is low, or if barriers to dispersal are present, extinction may result.

There are many cases where complete or local extinction has occurred because species were unable to disperse rapidly enough when climate changed. For example, a large, diverse group of plant genera, including watershield (*Brassenia*), sweet gum *(Liquidambar)*, tulip tree *(Liriodendron)*, magnolia *(Magnolia)*, moonseed *(Menispermum)*, hemlock *(Tsuga)*, arbor vitae *(Thuja)*, and white cedar *(Chamaecyparis)*, had a circumpolar distribution in the Tertiary. But during the Pleistocene ice ages, all went extinct in Europe while surviving in North America. Presumably, the east-west orientation of such barriers as the Pyrennes, Alps, and the Mediterranean, which blocked southward migration, was partly responsible for their extinction (Tralau 1973).

Other species thrived in Europe during the cold periods, but could not survive conditions in postglacial forests. Some were unable to extend their ranges northward in time and became extinct except in cold, mountaintop refugia (Seddon 1971).

These natural changes were comparably slow: Change to warmer conditions at the end of the last ice age spanned several thousand years, yet is considered rapid by natural standards (Davis 1983). We can deduce that, if such a slow change was too fast for many species to adapt to, the projected warming (perhaps 10 times faster) will have more severe consequences. For widespread, abundant species, like the loblolly pine modelled by Miller, Dougherty, and Switzer (1987), even substantial range retraction might pose little threat of extinction; but rare, localized species, whose entire ranges might become unsuitable, would be threatened unless dispersal and colonization were successful.

Could an average species successfully disperse given what we know about dispersal rates and barriers? If the climatic optima of temperate zone species do shift hundreds of miles toward the poles within the next 100 years, then these species would have to colonize very rapidly. A localized species might have to shift poleward at several hundred kilometers per century, or faster, in order to avoid being left behind in areas too warm for survival. Although some species, such as plants propagated by spores or dust seeds, may be able to match these rates (Perring 1965), many species could not disperse fast enough to compensate for the expected climatic change without human assistance (see in Rapoport, 1982), particularly given the presence of dispersal barriers. . Even wind-assisted dispersal may fall short of the mark for many species. For example, wind scatters seeds of the grass (*Agrostis hiemalis*), but 95% fall within 9 m of the parent plant (Willson, 1983). In the case of the Engelmann spruce, a tree with light, wind-dispersed seeds, fewer than 5% of seeds travel even 200 m downwind, leading to an estimated migration rate of between 1 and 20 km per century (Seddon 1971).

Figure 4 illustrates the difficulties to be faced by a population whose habitat becomes unsuitable due to climate change. Colonists (e.g. seeds) must run an obstacle course through various natural and human-created dispersal

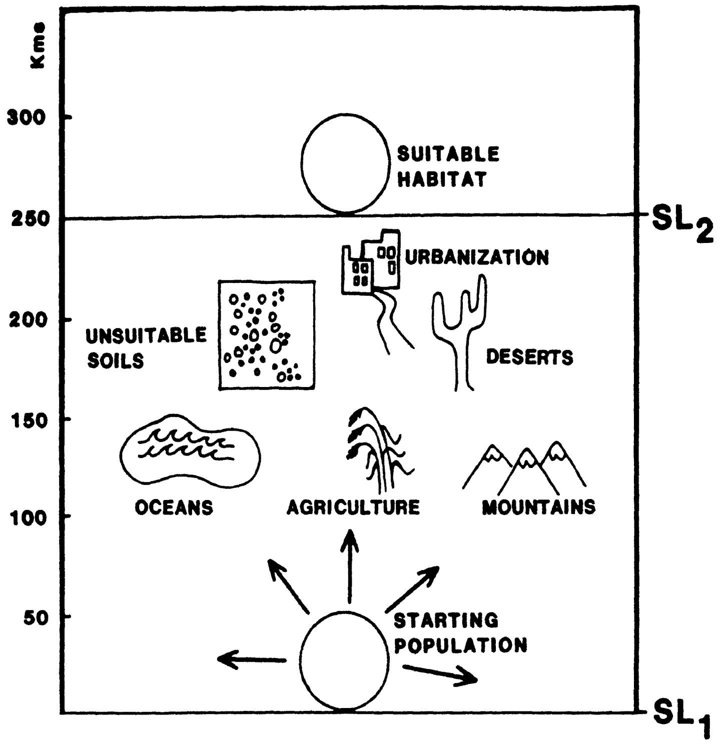

Figure 4.
Obstacle course to be run by species facing climatic change in a human-altered environment. To "win," a population must track its shifting climatic optimum and reach suitable habitat north of the new southern limit of the species range. SL1=southern limit after climate change. The model assumes a plant species consisting of a single population, which has its distribution determined solely by temperature. After a 3 degrees C. rise in temperature the population must have shifted 250 km to the North to survive, based on Hopkins bioclimatic law (MacArthur 1972). Shifting will occur by simultaneous range contraction from the South and expansion by dispersion and colonization to the North. Progressive shifting depends upon propagules that can find suitable habitat to mature and in turn produce propagules that can colonize more habitat to the North. Propagules must pass around natural and artificial obstacles like mountains, lakes, cities, and farm fields. The Englemann spruce has an estimated, unimpeded dipersal rate of 20 km/100 years (Seddon 1971). Therefore, for this species to "win," colonizing habitat to the North of the shifted hypothetical limit would require a minimum of 1,250 years.

(continued on Update Pg. 6)

barriers in a limited amount of time in order to reach habitat that will be suitable under the new climatic regime. For the example selected, with a dispersal rate of 20 kms per century, successful dispersal is highly improbable.

Although many animals may be, in theory, highly mobile, the distribution of some is limited by the distributions of particular plants; their dispersal rates may therefore largely be determined by those of co-occuring plants. Behavior may also restrict dispersal even of animals physically capable of large movements. Dispersal rates below 2.0 km/year have been measured for several species of deer (Rapoport, 1982), and many tropical, deep-forest birds simply do not cross even very small unforested areas (Diamond 1975). On the other hand, some highly mobile animals may shift rapidly, as did the European birds discussed above (Williamson, 1975; see also Edgell, 1984).

Even if animals are good dispersers, suitable habitat may be reduced under changing climatic conditions. For example, it has been suggested that tundra nesting habitat for migratory shore birds might be reduced by high-arctic warming (Myers, 1988).

Synergy of Habitat Destruction & Climate Change

What is likely to happen given the environmental conditions of the coming century? Some clear implications for conservation follow from the preceding discussion of dispersal rates. Any factor that would decrease the probability that a species could successfully colonize new habitat would increase the probability of extinction. Thus, species are more likely to become extinct if their remaining populations are small. Smaller populations mean fewer colonists can be sent out and that the probability of successful colonization is smaller.

Species are more likely to become extinct if they occupy a small geographic range, and it is less likely that some part of their range will remain suitable when climate changes. Further, if a species has lost much of its range due to some other factor, such as habitat destruction, it is possible that the remaining populations are not located in prime habitat. As such, they might now be found in that part of their historic range which is most susceptible to climate change.

As previously described, species are more likely to become extinct if there are physical barriers to the colonization, such as oceans, mountains, and cities (Fig. 4).

For many species, all of these conditions will be met by human-caused habitat destruction, which increasingly confines the natural biota to small patches of original habitat, patches isolated by vast areas of human-dominated urban or agricultural lands. This problem by itself threatens hundreds of thousands of plant and animal species with extinction within the next 20 years (Myers, 1979; Lovejoy, 1980).

Habitat destruction in conjunction with climate change sets the stage for an even larger wave of extinction than previously imagined, based upon consideration of human encroachment alone. Small, remnant populations of most species, surrounded by cities, roads, reservoirs, and farm land, would have little chance of reaching new habitat if climate change makes the old unsuitable. Few animals or plants would be able to cross Los Angeles on the way to new habitat. Figure 5 illustrates the combined effects of habitat loss and warming on a hypothetical reserve.

Need for Ecosystem and Autecological Studies

Attempts to understand how species and communities will respond to warming are in their infancy. Although the types of considerations discussed here make possible general projections of biotic response, it is complicated to understand effects on particular species, communities, or protected areas. For example, what effects might warming have upon muskox (*Ovibos moschatus*) in the arctic? At first glance it might seem that increased vegetation growth (Edlund, 1987) would favor it, as winter forage is often limiting (Harington, 1987). However, both muskox and caribou (*Rangifer tarandus*) populations can crash dramatically in the winter when, instead of cold, stable winters, there are periods of warmth. Wet snow can cover food supplies and then freeze, resulting in severe mortality (Harington, 1987). Further, Harington (1987) describes how ice connections between Canadian arctic islands are vital for migration of island populations of arctic mammals, like muskox; a warming trend could melt the ice and

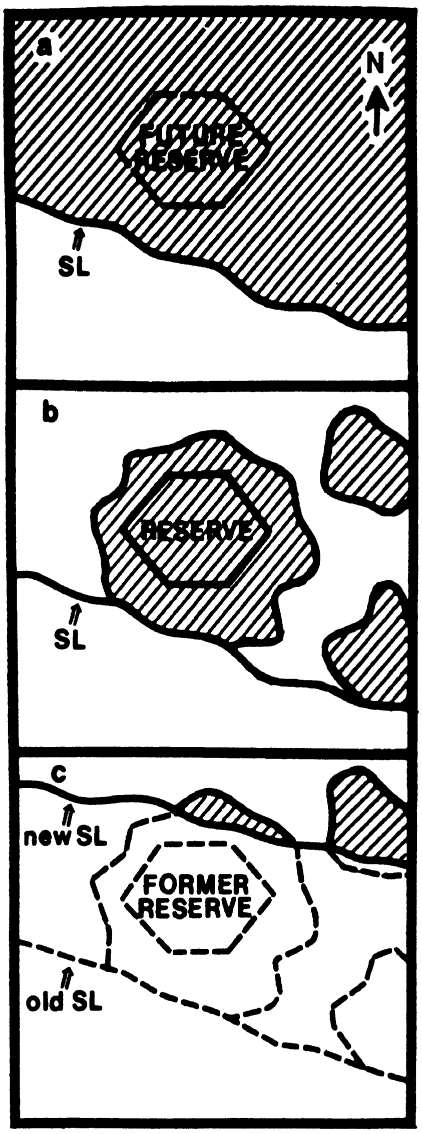

Figure 5.

How climatic warming may turn biological reserves into former reserves. Hatching indicates: (a) species distribution before human habitation, southern limit, SL, indicates southern limit of species range; (b) fragmented species distribution after human habitation; (c) species distribution after warming.

The most comprehensive conclusion, however, is that because species with fragmented populations and reduced ranges are so vulnerable to climate change, one of the best things that can be done now is to minimize further range reduction.

sever these connections. This example underscores the need for specific ecological studies on species, communities, and protected areas that might be impacted.

Endangered Species

Peters and Darling (1985) identified characteristics of populations that would leave them at greatest risk from climate change. Endangered species often have many of these traits:

1) They are usually geographically restricted, which, as discussed above, makes it less likely that some part of their range would remain suitable under changing conditions. They may already be restricted by other causes, especially habitat destruction, to regions that are presently climatically marginal.

2) Because endangered species have reduced populations, they may have reduced genetic variability, including that coding for adaption to different climate regimes or conferring tolerance of climatic variability.

3) They are often specialists and may depend upon the survival of one or a few other species, as in the Everglades kite (Rostrhamus sociabilis), which depends on the apple snail (*Pomacea caliginosa*) as its single food source.

4) Additionally, specific species may possess other traits that make them vulnerable, such as wintering in the arctic, where large changes are expected, or living in coastal habitats that would be inundated by sea level rise. The whooping crane (*Grus americana*), for example, may be at risk from flooding of its wintering area on Matagorda Island in Texas (Breckenridge, et al, 1988).

Implications for Management

See Peters and Darling (1985) for a further discussion. In brief, however, there are possible strategies to mitigate species loss. Better characterization of future regional climatic regimes is vital. Such information could be used to make better decisions about siting or modifying reserves. Corridors, for example, particularly in mountainous regions where dispersal distances need not be large, could provide avenues for dispersal. Similarly, managers of coastal marshes might wish to ensure that uplands are conserved in anticipation of when rising sea level forces marshes upward. Forewarning of local environmental trends might also allow reserve managers to prepare for active management of reserve conditions, as by irrigating to compensate for decreased rainfall. Climate-focused studies of potentially vulnerable species and communities should be undertaken.

On the other hand, not all the changes for wild systems would be negative. Some species would expand their ranges and have greater abundances. It has been suggested, for example, that some arctic-nesting waterfowl might expand their populations as conditions warm (Harington, 1986).

The most comprehensive conclusion, however, is that because species with fragmented populations and reduced ranges are so vulnerable to climate change, one of the best things that can be done now is to minimize further range reduction. Thus, climate change is a compelling new reason to conserve as many natural lands as possible.

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Book Review

Why Preserve Natural Variety? by Bryan G. Norton

In his most recent book sponsored by the Center for Philosophy and Public Policy at the University of Maryland, Bryan Norton explores the fundamental question, What is the endangered species problem? from a philosphical perspective. Until recently, species preservationists have found a theoretical basis for their policies in the "demand" value of wild species for fulfilling certain narrowly defined human needs or in controversial and badly understood proposals about the "intrinsic" values of species. Norton examines these rationales and diverges from them by pointing to new sources of value for wild species: they have worth because they can transform human values. In doing so, he also provides a fresh perspective environmental ethics more generally. The following excerpt from the preface of the book introduces the overall theme of the work and raises some of the questions which guided the project.

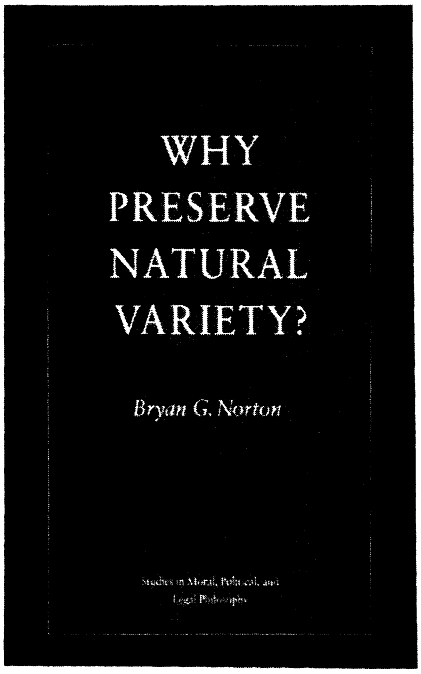
I have come to realize, after several years of intense work on endangered species policy, that the endangered species issue is not one, but a cluster of related problems. Viewed most narrowly, it is the question of what a relatively wealthy and fast-growing society should do when it discovers that the population of some species is so depleted that its continued existence is immediately threatened. In this view individual species are identified and a recovery program is proposed. Restrictions on"takings" are enforced and areas of "critical habitat" may be designated and protected. This narrow view of the problem was encouraged because citizen's awareness had developed after an act designed to list and protect every species, taken singly, had been implemented.

Other, more general, questions demand answers. What should be done to ensure that species which still have relatively healthy reproductive populations will not decline toward a minimum threshold where they will require individual attention? What should be done to reverse the general trend toward biological simplicity in North America and, especially, in tropical, developing countries? The endangered species problem can be viewed as a symptom of the pervasive tendency to convert more and more relatively natural ecosystems to intense human use. A thorough examination of endangered species policy must inquire whether this trend can and should continue indefinitely.

In accepting funding from the Ethics and Values in Science and Technology Program of the National Science Foundation for this project, we agreed to ask and propose answers to two questions: (1) What reasons can be given for a policy of preserving species? and (2) Given the most reasonable answer to (1), what should be done if financial and personnel resources are insufficient to protect all species?

These questions are addressed in the broadest context, the context in which identified, severely endangered species represent symptoms of the more general problems mentioned in the last paragraph. As a result, I have interpreted question (1) as requesting a rationale for a general policy protecting biological diversity. Why should a society be concerned to limit the destruction of the varied natural ecosystems and associations that provide the habitat for wild species? In this broad view of biological diversity, a species existing in varied habitats presents more diversity than does a species confined to a single "critical habitat." A single species existing in different associations faces varied competitive and selectional regimens. If the concern is with species diversity over the long run, these varied habitats represent alternative ecological and evolutionary trajectories, and this variety is essential to encourage genetic diversity in populations and, in the long run, speciation.

Similarly, I have not merely posed question (2) as one of interspecific priorities for preserving species. This narrow formulation of the priorities question is encouraged if we view the Endangered Species Act as a response to the critical endangerment of identifiable, individual species... The priorities question is best posed: How ought insufficient funds and efforts be spent to meet threats to biological diversity?... In this broad version, the problem of priorities becomes one of obtaining the best return on public resources. Besides being virtually impossible to apply intelligently, proposals to favor some categories over others fails to address the endangered species problem in its full magnitude...



Why Preserve Natural Variety? is published by Princeton University Press, 1987, Princeton, NJ 08540. It is available for $30.

Technical Notes

Produced by The Center for Conservation Biology at Stanford University

Landscapes, Topoclimate, and Conservation

by Stuart B. Weiss and Dennis D. Murphy

All landscapes exhibit ranges of microclimates created by topographic variation. These microclimates, or more specifically topoclimates, are primary determinants of the range of biodiversity within a geographic area. Since many species persist only in relatively narrow temperature ranges and hydrologic regimes, usually only subsets of potential habitats meet these requirements. As such, the analysis of topoclimates across the distribution of an endangered species can be a valuable first step in any conservation study.

Gross differences between north-facing and south-facing slopes are familiar to any casual landscape observer. More subtle but biologically important differences between slopes can be accurately quantified by calculating clear-day insolation striking surfaces of given azimuth and tilt. The resulting insolation values can be used as microclimate indices to assess or rank the habitat values of selected slopes. We used such calculations in untangling the roles of weather, topoclimates, and larval hostplant availability in the population dynamics of the bay checkerspot butterfly (*Euphydras editha bayensis*) a federally protected "threatened" species.

Rapid development of larvae and early emergence of adults is crucial in reducing mortality of the subsequent generation of the bay checkerspot butterfly in the short California grassland growing season. The timing and amount of rainfall in each rainy season (November-March) interact with phenological differences between topoclimates to determine the density and spatial distribution of the next generation of larvae across thermal gradients. The black larvae bask in direct sun, and studies of larval growth show relationships between calculated insolation and larval weight gains that can be used to predict the timing of adult flight and oviposition. Larvae on south-facing 11% slopes, for instance, can reach adulthood more than one month earlier than larvae on north-facing 20% slopes. Even small differences in azimuth and tilt, especially on cooler slopes, can significantly affect insolation and larval development times.

Topoclimate diversity in bay checkerspot habitat is important on at least three levels. The gross distribution of slopes determines the range and proportions of topoclimates within a habitat patch. Populations in habitat patches without cool exposures are highly susceptible to droughts. Habitats without warm slopes may result in adult flight too late for reproduction in certain years. A full range of topoclimates in a given habitat patch helps to insure that at least some individuals are in phase with the hostplant growing season. A second level of topoclimate diversity is less obvious. Mark-capture experiments show that larvae can travel 10-15 meters/day and reach warmer topoclimates, thus advancing their development by as much as a week or more. The spatial arrangement of cool and warm topoclimates within a habitat patch, therefore, can have a marked influence on habitat quality. Third, microtopography on a scale as small as 10 cm can be important. For example, slopes terraced by cattle grazing can afford larvae areas of direct sun when the rest of a slope is in shade.

Understanding topoclimatic requirements and variation can be a key tool in the conservation of the earth's less obvious but greatly threatened species.

These results bear on the conservation of other endangered butterflies. The hostplant of the San Bruno elfin (*Incisalia mossii bayensis*) thrives on north-facing rocky slopes and colonizes old road cuts and quarries. During the March flight season of the elfin, steep (>35°) north-facing roadcuts are deeply shaded and unavailable as habitat. Hostplants on steep slopes with northeast or northwest exposures, however, receive adequate morning or afternoon sun to provide habitat.

Topoclimates are also affected by exposure to wind, fog, and cold air drainage. The mission blue butterfly (*Plebejus icarioides missionensis*) is not found in habitats dominated by its hostplant lupine species where those sites are particularly exposed to strong prevailing winds. The callippe silverspot butterfly (*Speyeria callippe callippe*), a candidate for federal protection, flies during the summer fog season and cannot use its violet hostplants in large areas that are frequently subject to fog conditions. Low-lying areas which have cold air pools at night are particularly prone to early and late season frosts, with concomitant impacts on habitat suitability for numerous organisms. Such information is currently being considered in recovery and habitat restoration efforts that target the species discussed above.

While butterflies are as a group particularly sensitive to thermal conditions, other ectothermic organisms also respond to topoclimates. Understanding topoclimatic requirements and variation thus can be a key tool in the conservation of the earth's less obvious but greatly threatened species.

Bulletin Board

Ornithology Photo Library

VIREO (Visual Resources for Ornithology), the world's largest library of bird photographs, is located at the Academy of Natural Sciences of Philadelphia. The collection, which includes photos of nearly half the world's birds, is available for scientific, educational, conservation, and commercial use. A slide set of endangered birds of North America will soon be available. For more information, contact VIREO, Academy of Natural Sciences, 19th and the Parkway, Philadelphia, PA 19103 (215) 299-1069.

Biological Diversity Legislation (H.R. 4335)

Reps. Scheuer (D-NY) and Claudine Schneider (R-RI) have introduced H.R. 4335, the National Biological Diversity Conservation and Environmental Research Act. The Act finds that increased ecological and biological research is needed to overcome gaps in our knowledge about biological diversity which hamper resource management decisions; and that existing laws are inadequate and poorly coordinated. The bill aims to save the diversity of living organisms in their natural habitats.

The Act would make efforts to conserve biological diversity a national priority. Methods to accomplish this include requiring explicit consideration of biological diversity in environmental impact documents and development of a federal strategy by the major management and research agencies. A Scientific Advisory Committee would provide technical expertise; a National Center for Biological Diversity and Environmental Research would assess and coordinate database and research efforts and make this information available to policy-makers. Finally, a system of partnership grants would stimulate private individuals and organizations and states to carry out the strategy.

Single copies of the bill may be obtained by sending a self-addressed, stamped envelope to the House Document Room, U.S. Capitol, Washington, D.C. 20515.

NRCC Newsletter

The Northern Rockies Conservation Cooperative is an independent, non-profit , non-membership organization which carries out ecological research, environmental education, organizational development, and policy analysis directed at species and ecosystem conservation. As NRCC begins its 2nd year of operation, they have initiated publication of a newsletter designed to inform readers of the work and accomplishments of the organization as well as their future plans. For more information about the new NRCC newsletter as well as other publications and activities, contact NRCC, Box 2705, Jackson, Wyoming 83001, (307) 733-6856.

Conference on the Consequences of Global Warming for Biodiversity

World Wildlife Fund is convening a major conference on Consequences of Global Warming for Biological Diversity, October 4-6, 1988, in Washington, D.C. The conference is sponsored by the National Science Foundation, U.S. Environmental Protection Agency, Joyce-Mertz Gilmore Foundation, Department of Energy, Smithsonian Institution, and U.S. National Parks Service. For information, contact Stacy Roberts, World Wildlife Fund, 1250 24th St, N.W., Washington, DC 20037 (202 778-9572).

Endangered Species
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