Preparing for an Uncertain Climate—Vol. II

October 1993

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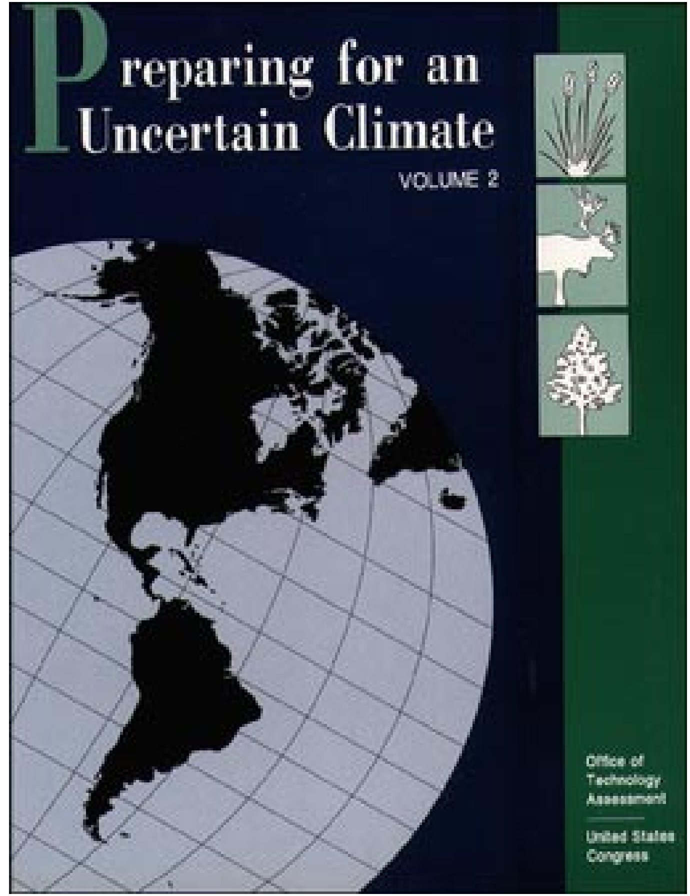

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Foreword

Preparing for an Uncertain Climate is OTA's second report on climate change. In 1991, we published *Changing by Degrees: Steps to Reduce Greenhouse Gases,* which focused on ways to reduce the buildup of greenhouse gases in the atmosphere. Slowing the rate of growth in these emissions continues to be very important, but most analyses conclude that despite international efforts, the Earth is likely to warm several degrees over the next century.

Climate change poses many potential problems for human and natural systems, and the long-term effects of climate change on these systems are becoming increasingly important in public policy, For example, international agreements were recently signed on both climate change and biodiversity. Recognizing the potential problems, Congress asked OTA to examine how the Nation can best prepare for an uncertain future climate. This assessment tackles the difficult tasks of assessing how natural and human systems may be affected by climate change and of evaluating the tools at our disposal to ease adaptation to a warmer climate. Volume 1 addresses coastal areas, water resources, and agriculture; volume 2 includes wetlands, preserved lands, and forests.

OTA identifies more than 100 options in the full report that could help ease the transition to an uncertain climate. We categorized a subset of these options as ''first steps. ' Options that fall into this group are near-term concerns because they will take a long time to complete, address ''front-line" or urgent issues that need attention first in order to make better decisions later, can be approached through efforts already under way, are beneficial for reasons other than helping to prepare for climate change, or represent near-term 'targets of opportunity.''

The United States has put in place an ambitious Global Change Research Program to ''observe, understand, and ultimately predict global and regional climate change. " This effort, which has so far been based overwhelmingly in the physical sciences, is not geared to help make natural resource planning and management decisions, to identify ecosystem-level responses to climate change, or to readily provide policy guidance on mitigation or adaptation. While scientists continue to reduce uncertainty, policy makers will continue to reauthorize environmental legislation, manage natural resources, and develop energy policy. Having mechanisms for integrating research and evaluating reasonable policy routes while we are completing the science would be a valuable addition to the Federal effort. This assessment could help guide these needed improvements.

Preparing for an Uncertain Climate was requested by three congressional committees: the Senate Committees on Environment and Public Works and on Commerce, Science, and Transportation, and the House Committee on Science, Space, and Technology. OTA appreciates the support this effort received from hundreds of contributors. Workshop participants, reviewers, contractors, and informal advisors gave us invaluable support as we attempted to sift through the voluminous material on this subject. OTA, however, remains solely responsible for the contents of this report.

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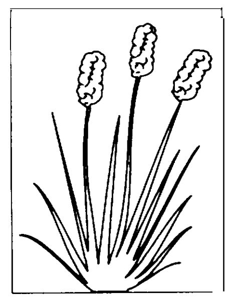
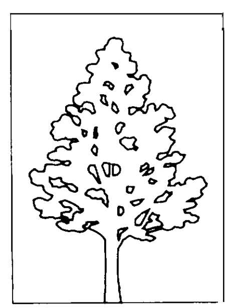
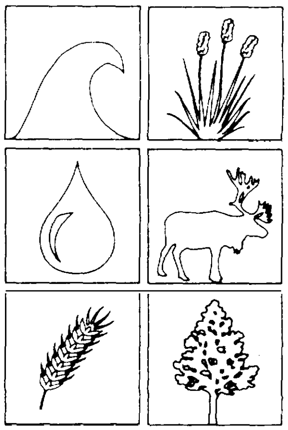




Synthesis, Summary and Policy Options 1

Widespread public attention to the question of whether or not climate is changing intensified during the hot summers of the late 1980s. Since then, during the time the Office of Technology Assessment (OTA) was conducting this assessment, the Nation has experienced major drought in the western and southeastern United States, powerful hurricanes in Florida and Hawaii, a destructive forest fire in Northern California, and substantial flooding in the Midwest. Although none of these events can be clearly linked to climate change, they represent the types of extreme events that may occur with greater frequency if climate warms.

Most scientists believe that the Earth's climate is likely to warm by several degrees during the next few decades. Although our understanding of climate change has progressed a great deal in the past few years, major knowledge gaps remain, and empirical evidence of human-induced climate change is not unequivocal. Many factors important to understanding climate, such as the role of clouds, ocean circulation, and solar cycles and the interactions between living organisms and the environment, cannot yet be reliably incorporated into general circulation models (GCMS), science-based computer models used to predict potential changes in average global surface temperature. Some key information that could guide policy response is likely to remain unknown for another decade or two (69). We cannot predict rates or magnitudes of changes in local or regional temperature and precipitation patterns. Predicting changes in the variability of climate and weather patterns, particularly on small spatial scales, is also beyond current scientific capabilities. Existing ecological, social, and economic models are similarly limited and cannot adequately predict the responses to climate



changes by natural systems (e.g., forests and wetlands) or managed systems (e.g., water resource systems and agriculture). Therefore, most policy decisions made in the near future about how to respond to the specter of climate change will be made in light of great uncertainty about the nature and magnitude of potential effects.

Although climate change has certainly become a public and scientific concern, what to do about it is not clear. Issues now being heatedly debated are the technical feasibility and economic implications of reducing or offsetting emissions of greenhouse gases. Several studies concluded that cutting U.S. emissions of carbon dioxide (CO_2), the most important anthropogenic greenhouse gas, below current levels is plausible. OTA's 1991 report, *Changing by Degrees: Steps to Reduce Greenhouse Gases,* concluded that by adopting a package of low-cost measures, the United States could significantly slow the growth of its CO_2 emissions over the next 25 years-but could not easily decrease them to below current levels (172). With aggressive-but potentially expensive--initiatives, OTA found that the United States might be able to decrease its CO_2 emissions to 35 percent below today's levels by 2015. Even in this case, U.S. emissions of $C0_2$ are expected to rise again after 2015 unless there are successful programs for developing alternatives to fossil-energy supplies (such as solar and nuclear power)-programs that would lead to substantial increases in market penetration of one or more of these energy alternatives by 2015.

Since the 1992 United Nations Conference on Environment and Development (UNCED) in Brazil, many countries have signed the Climate Convention, seeking to freeze greenhouse gas emissions at 1990 levels in the near future. On Earth Day 1993, President Clinton announced that the United States would participate in this effort. The Climate Convention represents a landmark agreement and recognition that global environmental problems must be addressed on a global scale.

Nonetheless, the bulk of scientific evidence indicates that simply freezing greenhouse gas emissions at 1990 levels will not stop global warming. *Stabilizing emissions* is different from *stabilizing atmospheric concentrations.* Constant annual emissions will still increase the total concentration of greenhouse gases and, thus, the heat-trapping capacity of the atmosphere. The Intergovernmental Panel on Climate Change (IPCC), an international group representing more than 50 countries, concluded that to stabilize the concentrations of greenhouse gases in the atmosphere at today's levels would require up to an 80 percent reduction in world CO_2 emission levels immediately, along with significant reductions in other greenhouse gases. Even if such reductions could be achieved, the world would warm about 1 to 4 OF (1 to 2 'C) because of long-lived greenhouse gases emitted over the last century. Given the virtual certainty that energy use (and associated $C0_2$ emissions) in developing countries will rise as they pursue economic growth, and given the intense debate in the United States and other industrialized countries about the feasibility of achieving even a freeze in emissions, it seems certain that global atmospheric concentrations of greenhouse gases will continue to rise. Thus, unless the predictive GCMS are seriously flawed, average global temperatures are expected to increase several degrees over the next century, even under the most optimistic emissions scenarios (see box 2-B).[1]

If climate change is inevitable, then so is adaptation to climate change. Society and nature may have to cope with rising sea levels, more frequent drought and periods of temperature extremes, changes in water supplies, disruption of ecosystems, and changes in many other climate-sensitive natural resources (see ch. 2). The term *adaptation, as* used here, means any adjustment to

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1 All chapters, boxes, figures, and tables cited here can be found in volumes 1 and 2 of this report. Volume 1 addresses coastal areas, water resources, and agriculture; volume 2 includes wetlands, preserved lands, and forests.

altered conditions; it can be a biological, technical, institutional, regulatory, behavioral, or economic response. It encompasses *passive adjustments (e.g.,* biologically driven changes in plant communities or gradual changes in human behavior and tastes), *deliberate reactive responses* (management responses after climate change effects are observed), and *anticipatory actions,* (plannin g, engineering, or regulatory responses taken in preparation for climate change). Throughout this report, we examine the ability of natural-resource-based systems, both unmanaged and managed, to adapt to climate change and consider means by which adaptation can be enhanced by modifying management, advancing research and technology, disseminating information, and taking legislative actions.

Given the current inability to predict accurately where, when, and how much change will occur, decisionmakers must plan for natural and managed systems in light of considerable uncertainty. It is understandable, under these circumstances, that postponing responses until more is known about climate change is very appealing. Nonetheless, uncertainty does not mean that the Nation cannot position itself better to cope with the broad range of impacts possible under climate change or protect itself against potentially costly future outcomes. In fact, delay in responding may leave the Nation poorly prepared to deal with the changes that do occur and may increase the possibility of impacts that are irreversible or otherwise very costly. Many options that will increase the Nation's ability to cope with the uncertainties of climate change will also help in dealing with existing threats to natural resource systems, such as those related to climate extremes (e.g., droughts, floods, and fire) and the fragmentation of natural habitat.

The following sections of this chapter discuss the OTA assessment, general problems posed by climate change, criteria for choosing strategic responses, near-term opportunities for Congressional action, and summaries and frost steps for the six resource systems studied in detail.

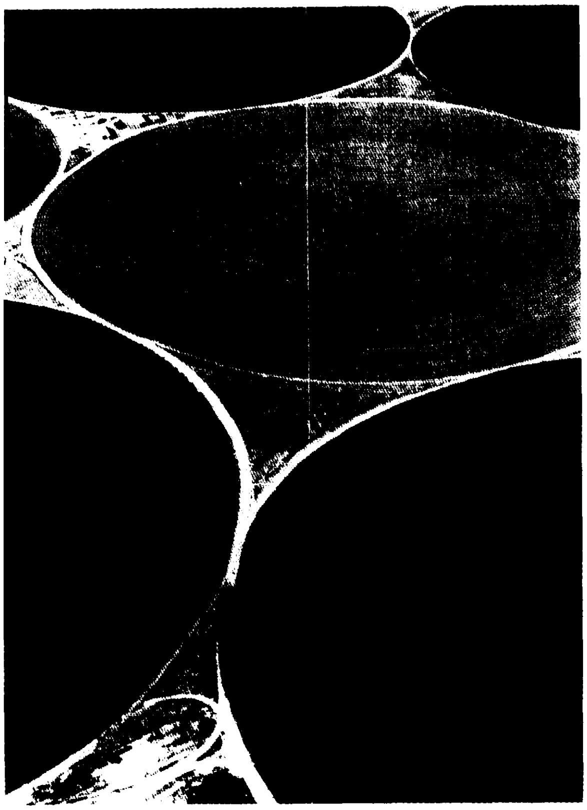
THE OTA ASSESSMENT

Three Committees of Congress asked OTA to help them think about coping with potential climate change. OTA was asked: How can the United States set prudent policy, given that we do not know for certain what the climate will be? This assessment attempts to answer three key questions:

- What is at risk over what time frames? Which natural ecological systems and managed natural resource systems are at risk from climate change? How do the lead times needed for human interventions in these systems vary?
- How can we best plan for an uncertain climate? When and how should decisionmakers consider the uncertain effects of a changing climate as they plan the future management of natural and managed systems in the United States? What criteria should be used?
- Will we have answers when we need them? Does the current U.S. Global Change Research Program (USGCRP) reflect the short- and long-term needs of decisionmakers? Will it provide information about rates of climate change, the potential for ''surprise' effects on different systems, potential strategies for making systems more resilient in the face of uncertain climate change, and adapting to the changes that may occur?

Society depends on natural and managed systems for both basic needs and amenities. These include, for example, food, shelter, clothing, drinking, energy, and recreation. Many social and economic problems arise when the availability and diversity of goods and services decline. Such disruptions can range fromd to severe, and they include unemployment, famine, migration of workers, and political instability. Climate change heightens the uncertainty about future availability of desired goods and services.

US AGRICULTURAL RESEARCH SERVIC



In the West, center-pivot sprinklers irrigate wheat, alfalfa, potatoes, and other crops. Increasingly efficient irrigation techniques may be critical if regional climates become drier.

Yet, given the potentially long delays until the onset of significant changes, reacting to climate change as it occurs may seem more practical than undertaking anticipatory measures. Why adopt a policy today to adapt to a climate change that may not occur, for which there is significant uncertainty about regional impacts, and for which benefits of the anticipatory measure may not be seen for decades? Effort put into adopting the measure could well be wasted. Furthermore, future generations may have more sophisticated technologies and greater wealth that can be used for adaptation (91).

The Committee on Science, Engineering, and Public Policy (COSEPUP) (27)[2] concluded that it is theoretically possible to put technology and practices into place to adjust to the changing climate as it happens if the change is gradual enough. However, the rate of climate change is, admittedly, unknown. FCC concluded: "it is uncertain whether these changes-should they come--would be gradual or sudden" (68). Furthermore, "our imperfect understanding of climate processes . . . could make us vulnerable to surprises; just as the human-made ozone hole over Antarctica was entirely unpredicted" (69).

Waiting to react to climate change may be unsatisfactory if it is possible that climate change impacts will be very costly. Of greatest concern may be those systems where there is the possibility of surprise-of facing the potential for high costs without time to react--or where the climate change impacts will be irreversible. Such impacts seem more likelvif long-lived structures or slow-to-adapt natural systems are affected, if adaptive measures require time to devise or implement, or if current trends and actions make adaptation less likely to succeed or more costly in the future. In these cases, anticipating climate change by taking steps now to smooth the path of adaptation may be appropriate.

Ideally, a policy-relevant research program could help identify appropriate actions as the current state of knowledge evolves. In response to the potential risks of climate change and the uncertainties surrounding the science, the Federal Government launched a massive, multiagency research effort in 1989 to monitor, understand,

2 COSEPUP's 1992 report, a joint publication of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, stated: "While inventions and their adoption may occur quickly, we must ask whether the broad spectrum of current capital investments could be changed fast enough to match a change in climate in 50 to 100 years" (27). The report goes on to note that half a century should be time enough to allow most major technological systems (and some natural systems) to be transformed and most capital stock to turn over.

and, ultimately, predict global changes and to determine the mechanisms influencing these changes (25, 26). Chapter 3 examines the USGCRP and suggests ways to effectively broaden the program to both incorporate natural resource concerns and assessment activities.

Other studies have examined systems at risk from climate change in various ways (see boxes I-A, l-B, and 2-F and refs. 27, 67, and 188). To complement these analyses, OTA focused its examination of adaptation potential on areas where:

- Costs of climate change may be very high. For example, flood and wind damages from more-intense storms could lead to death and extensive property damage.
- Impacts of climate change may be irreversible. For example, species extinction and loss of valuable ecosystems—in wetlands, forests, and wilderness areas-may be permanent.
- The validity of long-term decisions made today will be affected by climate change. For example, trees planted with a life expectancy of many decades may not survive to maturity if climate conditions change, Agricultural and coastal development in climate-sensitive areas may add to the likelihood of future losses to natural disasters.
- Preparing for catastrophic events is already warranted. Reacting to climate change may mean reacting to climate extremes-such as floods, droughts, storms, and frees. Coordinated contingency planning can help avert high costs and reduce risk of loss.
- There is a significant Federal role in the research, planning, or management of these systems.

On the basis of these criteria, OTA selected six systems for further analysis:

1. coastal areas,
2. water resources,
3. agriculture,
4. **wetlands,**
5. preserves (federally protected natural areas), and
6. forests.

The first three systems are managed natural-resource-based systems with a high degree of government involvement and a complex system of incentives and subsidies in place; these are grouped together in volume 1 of the report. The other three systems include less-managed natural systems and are presented together in volume 2. Both volumes contain this summary chapter, a primer on climate change, and a chapter on the Federal research effort. Box 1-A highlights our overall methodological approach.

Each of the six systems OTA examined is stressed to some degree today, and that may influence how well it can respond to any change in the future. For example, because populations in coastal areas are growing, the exposure to costly natural disasters is increasing. Water scarcity and water-quality concerns are already common in many parts of the United States. Current agricultural support programs often distort and constrain choices about crop and farm management. Wetland loss continues-albeit at a much slower rate than 20 years ago--despite a stated national goal of “no net loss’ (see vol. 2, ch. 4). Preserved natural areas serve aesthetic, recreational, and biodiversity functions, but may not be adequate in size or distribution to maintain wildlife and plant species in the face of growing habitat loss and fragmentation. U.S. forest managers are finding it increasingly difficult to meet the sometimes competing demands for recreation, environmental services, and commercial wood products.

Water is an integral element of all of the resource systems discussed in this report. Its abundance, location, and seasonal distribution are closely linked to climate, and this link has had much to do with where cities have flourished, how agriculture has developed, and what flora and fauna inhabit a region. Water quality and quantity will remain key to the economy. Future

Box l-A–The OTA Study in Context

Within the past 5 years, three major studies of the impacts of climate change have been released. The Environmental Protection Agency (EPA) (166) and the Committee on Science, Engineering, and Public Policy (COSEPUP) (27) issued reports on potential effects of global climate change on the United States; Working Group II of the Intergovernmental Panel on Climate Change (IPCC) focused on potential impacts from climate change worldwide (67).

The Sensitivity and Adaptability of Human Activities and Nature

Human activity and nature	Low sensitivity	Sensitive; adaptation at some cost	Sensitive; adaptation problematic
Industry and energy	✓		
Heatth	✓		
Farming		✓	
Managed forests and grasslands		✓	
Water resources		✓	
Tourism and recreation		✓	
Settlement and coastal structures		✓	
Human migration		✓	
Political tranquility		✓	
Natural landscapes			✓
Marine ecosystems			✓

SOURCE: Redrawn from Committee on Science, Engineering, and Public Policy, Panel on Policy Implications of Greenhouse Warming, National Academy of Sciences, National Academy of Engineering, and Institute for Medicine, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base* (Washington, DC: National Academy Press, 1992).

COSEPUP divided human activities and natural systems into three classes of sensitivity and adaptability to climate change: 1)low sensitivity, 2) sensitive but can adapt at a cost, and 3) sensitive with problematic adjustment or adaptation (see table). The report concluded that industry decisionmaking horizons and building schedules are shorter than the time frame within which most climatic changes would emerge, so most industries could be expected to adapt as climate shifts. COSEPUP listed human migration and water resources as "sensitive to climate change," but adaptable "at some cost." Finally, it suggested that unmanaged natural ecosystems respond relatively slowly and that their ability to adapt to climate change is more questionable and "problematic" than that of managed cropland or timberland. The EPA report concluded that natural ecosystems have only limited ability to adapt if the climate changes rapidly and suggested that "managed systems may show more resilience."

The Office of Technology Assessment (OTA) analysis began with the EPA, COSEPUP, and IPCC reports and related literature, but it goes beyond them In several important ways. COSEPUP addressed natural systems primarily in the general terms of "natural landscape" and "marine ecosystems." However, natural systems are much more numerous and complex than this categorization suggests. We examine some natural systems in the United States at a much finer level of resolution (e.g., wetlands, forests, and preserved areas) and in different regions of the country.

We also consider systems under varying degrees of management intensity-from less-managed wilderness areas, wetlands, and some coastal systems, to systems managed for multiple uses, such as forests and rangelands, to intensively managed agricultural and commercial forestry systems. We consider each to be a system for which we can characterize outputs and inputs. We focus on the outputs that society cares about, whether for economic, recreational, aesthetic, or other reasons-in short, things about which policy is made.

While recognizing the value of climate predictions used in previous assessments, we chose to acknowledge the uncertainties of our changing climate by deliberately avoiding predictions linked to any particular climate change scenario. Instead, reexamine the vulnerabilities of natural resource systems to climate change, attempt to elucidate how different climate variables drive natural resource systems, and examine the types of planning and management practices that might help vulnerable systems adapt to a changing climate.

Timing is key to our analyses. In addition to the sensitivity of systems to climate change, the lead time needed for human interventions in these systems also varies, as does the time frame for systems to respond. Continuation of the structure, function, and services of many systems in an uncertain future depends on decisions being made today. In this report, we highlight how today's decisions about long-lived systems (e.g., forests and water resource projects) may determine how those systems respond to tomorrow's unknown climate.

Finally, and perhaps most importantly for Congress, our assessment examines the institutions and legislative framework that surround natural and built systems in the United States today. Whether or not a system can adapt to a changing climate may depend on how adaptable the institutions themselves are. Many systems transcend agency, geographic, or legislative boundaries; such fragmentation can impede adaptation. OTA identifies these rigidities and offers new legislative, coordination, planning, and management options to facilitate adaptation.

water availability is essential for continued services and functions from coasts, water resources, agriculture, preserves, wetlands, and forests. Competition for water, whether for irrigation, recreation, wildlife, or urban use, is likely to heighten in some regions of the country. Throughout the report, we highlight this and other intersecting issues in cross-cutting boxes, indicated by a bar of icons representing the six systems studied (see table l-l).

THE PROBLEM OF CLIMATE CHANGE

Climate change alters the baseline against which future actions are gauged. Our lifestyles, water supplies, and food supplies and other things society values from natural resources rely on a dependable, consistent, and sustainable supply. Our institutions and infrastructure presume that the past is a reasonable surrogate for the future. When designing reservoirs, for example, historic rainfall patterns are assumed to provide a good indication of the range of future patterns. A farmer plants knowing that at times, weather conditions will cause a crop to fail, but with the expectation-based on past climate-that the crop will succeed, in most years.

Climate change poses two potential problems for existing management strategies for resources: 1) increased unpredictability resulting from changing climate averages, and 2) increased risk of surprises or large-scale losses. These, together with the ‘‘background’ of increasing population, greater future demand, and growing competition for the use of scarce resources, make the need to improve the Nation's ability to deal with an uncertain climate all the more urgent.

Stresses on resources are most acute and visible during extreme events such as floods and droughts. Our response to such events has often proven to be expensive and unsatisfactory. Damages from the Mississippi River flooding in 1993 are expected to range from $5 billion to $10 billion, with Federal disaster payments of about $3 billion. Almost $4 billion in Federal payments went to farmers suffering crop losses during the 1988 drought. Hurricane Hugo cost the Federal Government about $1.6 billion. Hurricane Andrew topped $2 billion in Federal disaster payments, and many complained about the Government's response.[3] Policies that improve the Nation's ability to prepare for and cope more effectively with climate hazards (e.g., floods, frees, and droughts) would be valuable now and would help prepare the Nation for a less certain future.

3 Hurricane Andrew's estimated cost to property insurers as of February 1993 is at least $15.5 billion (136). Additional losses involved uninsured property, public utility equipment (e.g., power lines), crop damage, property insured under the National Flood Insurance and the Small Business Administration programs, lost tax revenue, and the costs of emergency services.

Table 1 -l—List of Boxes in Report[a]

What Is at Risk?

As described in chapter 2, climate change predicted by the models includes changes in precipitation patterns, increased temperature, increased evaporation, and sea level rise. The combination of these factors could cause significant impacts on all systems. For example, sea level rise could lead to higher storm surges and

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[a] Shading indicates boxes that discuss interactions across resource systems

increased erosion of coasts (see vol. 1, ch. 4). Shifts in precipitation patterns could cause more floods, droughts, water-supply disruptions, hydropower reductions, and groundwater overdrafts, especially in the arid West (see vol. 1, ch. 5). The ideal range for agricultural crops might move north as temperatures increase, and drought losses could become more frequent (see vol. 1, ch. 6). Forests could experience more-frequent fire and diebacks driven by drought, insects, and disease (see vol. 2, ch. 6). It could become difficult to retain unique assemblages of plants and animals in preserves as the climate to which they are adapted effectively shifts northward or to higher elevations (see vol. 2, ch. 5). With sea level rise, loss of coastal wetlands may be accelerated, and regional drying could eliminate some prairie potholes (see vol. 2, ch. 4).

The loss of soil moisture that might result from higher evaporation rates at warmer temperatures is likely to present the greatest threat to natural systems. Figure 1-1 shows areas of the United States that may undergo significant changes in soil moisture based on climate changes projected by two GCMS. The Goddard Institute for Space Studies (GISS) scenario suggests that large areas face moderate drying. The Geophysical Fluid Dynamics Laboratory (GFDL) scenario shows more severe drying across much of the eastern and central United States. Figure 1-2 illustrates the

EOSAT CORP., 1993. REPRODUCED WITH PERMISSION.

The summer floods of 1993 in the Midwest demonstrate the risks of floodplain development combined with intensive control of river flow. The satellite photograph on the top shows the Mississippi River as it appeared in July of 1988 during the drought; the one on the bottom shows the same area during the floods of July 1993.

extent to which changes in soil moisture could affect U.S. lands in natural cover (e.g., forests and wetlands) or agricultural use. Much of the Nation's natural resource base may face at least moderate drying, which is likely to increase stress on vegetation.

It is impossible to estimate with any confidence the cost of climate change to society. Estimates of the costs to the United States resulting from an average temperature increase of **4 to 5** OF **(2 to 3°C)**[4] **range from 0.3 to 2.0** percent of the gross national product (GNP) (22, 23)---corresponding to tens of billions of dollars per year. Box 1-B highlights a broad range of climate impacts that could be caused by climate: change.

Although it is desirable to anticipate climate change, the uncertainties involved make the design of appropriate policies challenging. These uncertainties include: 1) the extent of global and regional climate change, 2) its economic and ecological impacts, and 3) the ability of society to adapt.

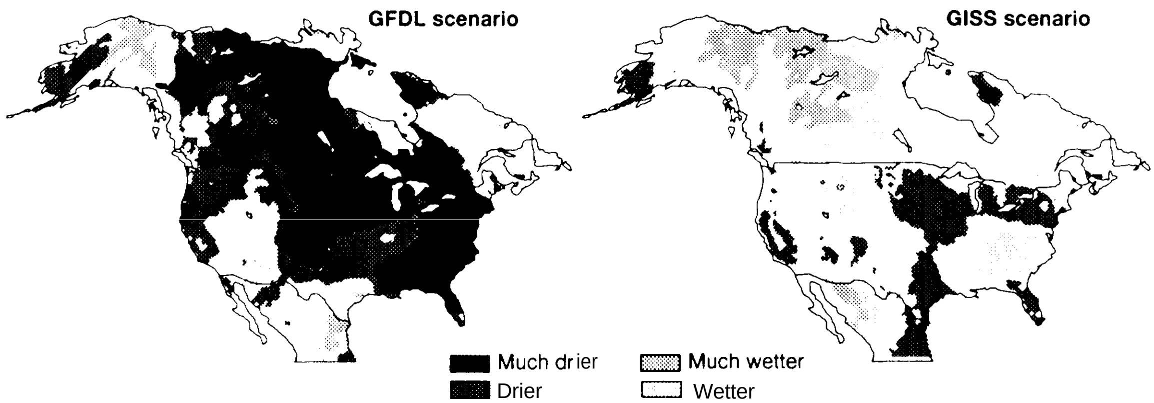
Uncertainties About Global and Regional Climate Change

Atmospheric scientists generally agree about the direction of climate change on a global and latitudinal scale. Global temperatures will likely rise, which would cause an increase in global precipitation and sea levels. Temperature increases are likely to be greater at higher latitudes. Winter precipitation could increase in middle and high latitudes; decreased summer precipitation in midcontinental, midlatitude regions could result in reduced summer soil moisture (69). At finer spatial scales, such as at the regional or State level, uncertainty about climate change increases.

The rate of change is also uncertain. IPCC estimated that global average temperatures will increase at over 0.5 OF (0.3 'C) per decade. As average temperatures increase, the entire range of expected temperatures increases as well; thus, both the warmest and coolest temperatures experienced will be warmer than before. This does not preclude late frosts or early freezes if variability increases. Some analyses show that climate variability may increase at the regional level—a series of warm years in a region could be followed by a series of cool years (195). There is, however, significant uncertainty about whether the frequency and intensity of extreme events will change. It is likely that, on average, precipitation worldwide will increase with climate change (69), but the models suggest that the interior of continents will get drier. It is not known whether droughts or floods will increase or decrease.

[4] This temperature increase is the estimated equilibrium warming from an atmosphere containing a greenhouse gas concentration equivalent to a doubling of CO_2 above preindustrial levels. Although the atmospheric concentration of gases leading to this temperature change is expected by about 2030, due to time lags, any resulting temperature effect might not be fully realized until several decades later.

Figure I-l—Potential Soil-Moisture Changes Under Two GCM Climate Change Scenarios



NOTE: GFDL=Geophysical fluid Dynamics Laboratory; GISS=Goddard Institute for **Space** Studies.

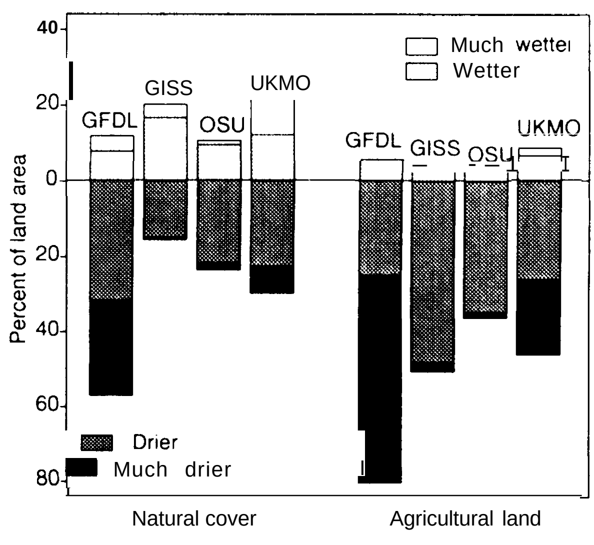
SOURCE: P.N. Halpin, "Ecosystems at Risk *to* Potential Climate Change," contractor report prepared for the Office of Technology Assessment, June **1993.**

Some analyses predict that hurricane intensities could increase (43), and drought in lower latitudes could be more severe (144).

Uncertainties About Direct Effects

Even if the regional changes in climate could be predicted, important uncertainties would remain about the physical and biological effects they would have. We do not really know how vegetation, animals, and other natural resources will be affected by climate change. Rising concentrations of atmospheric CO_2 will change the rates at which plants grow, respire, use water, and set seeds. Numerous laboratory experiments on intensively managed agricultural systems suggest that CO_2 will boost plant growth and productivity as long as other nutrients are plentiful (6, 39,81); this is called the CO_2 *fertilization effect (see* ch. 2). This effect has not yet been studied in many natural ecosystems (72, 124). Many studies of climate effects have used statistical models that relate natural vegetation or crop productivity to differences in current regional climates in order to estimate impacts under climate change scenarios. These are summarized in chapter 2 and in volume 1, chapter 6. The ability of plants and animals to

Figure 1-2-Soil-Moisture Changes for Agricultural Lands and Areas of Natural Cover, by GCM Climate Change Scenario



NOTE: Bars above the zero axis show the percent of land area becoming wetter; bars below the axis show the percent of land **area becoming drier. GFDL=Geophysical Fluid Dynamics Laboratory; GIS= Goddard Institute for Space Studies; OSU=Oregon State University;** and **UKMO-United Kingdom Meteorological Office.**

SOURCE: P.N. Halpin, 'Ecosystems at Risk to Potential Climate Change," contractor report prepared for the Office of Technology Assessment, June 1993.

Box 1-B-How Climate Change May Affect Various Systems[1]

Natural ecosystems-These may be the systems most vulnerable to climate change. We are least able to intervene and help with adaptation of natural ecosystems because of limited knowledge about ecological processes (see chs. 2 and 3). The shift in climate zones may far exceed the ability of vegetation, such as forests, to adapt through migration (see fig. 1-7). Climate zones may shift hundreds of miles in a century, whereas natural rates of dispersal and canonization maybe on the order of tens of relies in the same time period (35). in addition, fire and disease could result **in rapid dieback of many existing forests** and other terrestrial ecosystems (157). Helping plants to migrate through such activities as widespread seed dispersal would be very expensive and have dubious prospects for success (166). These issues are discussed in detail in "Forests" (vol. 2, ch. 6).

Climate change could also lead to a loss of species diversity. Isolated ("island") species may find themselves in climate zones that are no longer suitable for their survival (132). The potential for migration of plants and animals to new suitable habitats is not known, but barriers such as water bodies or development could impede migration (see fig. 1-6). Species in mountainous terrain could migrate to higher elevations. This creates reduced habitat areas, which are correlated with reductions in spades diversity. For example, a study ofa5"F (3 'C) warming **in** the Great Basin National Park in eastern Nevada concluded that it would cause 20 to 50 percent of species in individual mountain ranges to go extinct (106). The ability for human intervention to maintain species diversity in the face of climate change is currently limited. Selected species could be transplanted to new habitats, but this could be very resource intensive and would only be feasible in certain cases; little research has actually been done on transplantation of multiple-species systems. Migration corridors could be created, but their chances of success are limited because migration rates are slow and the direction of species migration is unknown. In addition, the creation of corridors maybe relatively expensive compared with setting aside new protected areas (154). These issues are discussed further in "Preserves: Federally Protected Natural Areas" (vol. 2, ch. 5).

Climate change can result in the loss of coastal wetlands directly through sea level rise, and indirectly, through interaction with societal response to sea level rise. Many coastal wetlands will likely be inundated because the sea will rise faster than wetland sediments accrue (161). Some wetlands will adapt to climate change by migrating upland with the rising tides. The areas with the greatest risk of wetland loss are along the Gulf and East Coasts of the United States (see fig. l-4). This will result in a net loss of wetlands because vast areas of tidal flats, such as in the Mississippi Delta, will be inundated, while inland migration will create new wetlands having only a fraction of the area of today's wetlands.[2] This net lose of wetlands will be even larger where coastal structures, such as bulkheads or levees, block the inland migration of wetlands (162).

Even if it were feasible to create new coastal wetlands, the costs of this would be so high that large-scale restoration programs would become unattractive. The average cost of creating wetlands has been estimated at roughly $20,000 to $45,000 **per acre ($50,000 to $100,000 per hectare),[3] not including land-acquisition costs.[4] This figure, however, can vary from just a few hundred dollars per acre to many hundreds of thousands of dollars per acre.Ilwugh technology is improving (see vol. 2, box 4-A), attempts to recreate wetland structure and function** fully have been limited. Prohibiting the construction of or removing coastal structures would enable more wetlands to colonize upland areas. It may not be feasible to move some existing ooastal structures that impede wetland migration. For example, it is unlikely that areas of dense development would be rebated.

1 **This box is a compendium of information drawn from previous studies, recent** research, **and** OTA's assessment. The **back chapters** of this report discuss **a subset of these issues.**

2 S. **Weatherman, University of Maryland at** College Park, personal communication, November 1992.

3 To **convert acres to hectares,** multiply by 0.405.

4 D. King, Chesapeake Biological Laboratory, University of Maryland, personal communication, **November 1$92.**

Prairie pothole and riparian wetlands in regions that get drier maybe at greater risk than those in regions that get wetter. For example, in the North Central States, increases in temperatures and evaporation rates could cause many prairie potholes to shrink or disappear, leading to further declines in already diminished continental waterfowl populations (9). Tundra may shrink as increased temperatures allow the permafrost to thaw and drain (see box l-G). In addition, wetlands of any type that are already degraded by pollution, water diversions, or fragmentation may also be particularly vulnerable (196, 199). The status and vulnerability of coastal, riparian, depressional, and tundra wetlands are discussed in "Wetlands" (vol. 2, oh. 4).

Fisheries-The potential effects of climate change on aquatic ecosystems have been studied very little to date, and could vary significantly. In some cases, marine fish may be able to migrate to new, more suitable habitats, depending on several factors, if food sources are available (80). Some freshwater fish in open waters, such as the Great Lakes, could benefit from a larger thermal niche (96). Fish in small lakes and streams, however, may suffer from increases in temperature that adversely affect survival, reproduction, or their ability to migrate to coder locations (101). Changes in water quality will also affect the survival of aquatic organisms. Climate change may alter circulation patterns in many lakes, reducing dissolved-oxygen concentrations. Higher temperatures will also act to reduce dissolved-oxygen concentrations (71). Sea level rise will increase saltwater intrusion of estuaries, potentially benefiting marine fish at the expense of freshwater species (60). However, changes in estuaries could have broad impacts on the U.S. fishery. By far, the greatest portion of commercial catches, with the exception of those from Alaskan fisheries, are composed of estuarine-dependent species (139). Ongoing alterations of critical habitat (such as those caused by geographic fragmentation and pollution) may be exacerbated by climate change. Box2-C (ch. 2) discusses, by region, the condition and value of fisheries today, current problems, and the potential impacts of climate change.

Agriculture-This system is very sensitive to climate, but climate change impacts maybe offset by intense management over short time frames. High temperatures and drought could reduce crop yields, although this effect could be counteracted by higher atmospheric concentrations of carbon dioxide and longer growing seasons in higher latitudes (129). The potential for agricuitural adaptation, particularly at the farm level, is very high (30). Changes in management practices (e.g., changing planting dates or using irrigation or crop-switching) can reduce or eliminate many of the potentially negative impacts of climate change. Shifts in climate zones would result in changes in relative productivity y levels, with some areas increasing output, and other areas reducing output due to increased competition (l). See "Agriculture" (vol. 1, ch. 6) for further discussion.

Coastal resources-Cities, roads, airports, and other coastal resources are vulnerable to flooding from sea level rise and hurricanes. The population near the coast is growing faster than populations in any other region of the country, and the construction of buildings and infrastructure to serve this growing population is proceeding rapidly. As a result protection against and recovery from hazards peculiar to the coastal zone, such as hurricanes and sea level rise, are becoming ever more costly (11). The combination of popularity and risk in coastal areas has important near-term consequences for the Safety of coastal residents, protection of property, maintenance of local economies, and preservation of remaining natural areas. These points are discussed further in "Coasts" (vol. 1, ch. 4).

Water resources-These resources are vulnerable to several climate change impacts. Changes in precipitation and higher levels of evapotranspiration can combine to affect surface-water and groundwater supplies, flood and drought frequency, and hydropower production. Arid basins could experience the largest relative change in water flow from climate change (67). Numerous studies have been conducted on the relative vulnerability of the major U.S. river basins to flood and drought, supply disruptions, hydropower reductions, groundwater overdrafts, and extreme events (46,49,66, 166). They conclude that the water resource regions most vulnerable to some or all of these events are the Great Basin, California Missouri, Arkansas, Texas Gulf, Rio Grande, and Lower Colorado (see fig. 1-5). See "water" (vol. 1, ch. 5) for more information; Appendix 5.1 lists State-by-State problems,

(Continued on next page)

Box 1-B--How Climate Change May Affect Various Systems--(Continued)

Human health--Climate change could affect human health, but there is a great deal of uncertainty about whether mortality and morbidity would actually increase and about the potential for adaptive measures (such as the use of air conditioning) to offset any negative impacts. Several studies have concluded that the potential range of infectious diseases could shift with climate change, but the exact nature of these shifts is uncertain (94). Even if the range of dbase-carrying vectors, such as mosqitoes, changes, enhanced pest-control measures could nullify the increased threat of disease. Effects of climate change in other countries could displace some populations. If "environmental refugees" lead to an increase in immigration, there is the potential for increased importation of communicable diseases into the United States (164). Other studies have shown that climate change could lead to increased cases of heat-stress mortality (74). Uncertainties about changes in human physiological and behavioral response make it difficult to draw conclusions about the risks of climate change to human health.

Energy--Higher temperatures will no doubt increase energy demand for cooling and decrease energy demand for heating. This would result in an increase in the demand for electricity (primarily for air conditioning) and for electric-generating capacity (93). This new demand would not be completely offset by reductions in the use of oil and gas for heating (96). The largest capital costs would be associated with increased power plant construction, which could cost as much as $170 to $920 billion, about 12 percent inure than the increases in capacity-needed to population and economic growth through the middle of the next century (93). As with sea level rise, adapting to increased energy demand could involve significant costs.

Transportation--Some forms of transportation could be positively or negatively affected by climate change. inland shipping maybe the most sensitive to climate change. On the one hand, warmer winters wouid likely result in less ice cover and a longer shipping season. For example, ice cover on the Great Lakes could be reduced by 5 to 13 weeks (4), lowering shipping and related costs (78). On the other hand, lower river flow and lake levels could increase shipping costs by reducing shipping tonnage capacity or blocking shipping (143). Some roads near the coast may have to be moved or protected from sea level rise. in many instances, adaptation is highly probable in transportation at some cost to the economy (see vol. 1, box 5-~ "Navigating the Mississippi through Wet and Dry Times").

adapt to changes in climate, either through physiological adjustment or through migration, is uncertain. Historically, trees can disperse and migrate about 60 miles (100 kilometers)[5] per century, but the projected rates of temperature change would require migration rates 5 to 10 times faster for forests to remain in suitable habitats (35, 36). The success with which natural vegetation can migrate will depend on seed dispersal, physical barriers to migration (e.g., mountains and developed land), competition between species, and the availability of fertile soils in areas of suitable climate.

Uncertainties About Society's Ability to Adapt

Finally, how society will respond to whatever climate change occurs and the resulting impacts are uncertain. Coping with climate change can take the form of technical, institutional, regulatory, behavioral, and economic adjustments. Future technologies and levels of income are unknown, although they will most likely improve and increase and will aid in adaptation (5). Will population growth or environmental consensus limit or expand adaptation options? Will people

[5] To convert miles to kilometers, multiply by 1.609,

Box I-B-How Climate Change May Affect Various Systems--(Continued)

The table below summarizes potential climate change impacts for these various systems.

Potential Climate Change Impacts for Various Systems

Systems	Potential impacts
Forests/terrestrial vegetation	Migration of vegetation. Reduction in inhabited range. Altered ecosystem composition.
Species diversity	Loss of diversity. Migration of species. Invasion of new species.
Coastal wetlands	Inundation of wetlands. Migration of wetlands.
Aquatic ecosystems	Loss of habitat. Migration to new habitats. Invasion of new species.
Coastal resources	Inundation of coastal development, Increased risk of flooding.
Water resources	Changes in supplies. Changes in drought and floods. Changes in water quality and hydropower production.
Agriculture	Changes in crop yields. Shifts in relative productivity and production.
Human health	Shifts in range of infectious diseases. Changes in heat-stress and cold-weather afflictions.
Energy	Increase in cooling demand. Decrease in heating demand. Changes in hydropower output,
Transportation	Fewer disruptions of winter transportation. Increased risk for summer inland navigation. Risks to coastal roads.

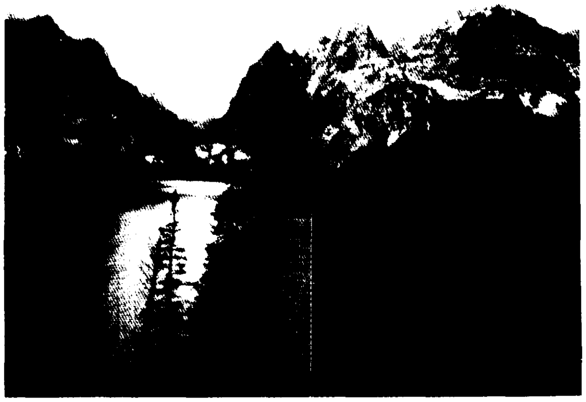
SOURCE: J.B. Smith and J. Mueller-Vollmer, "Setting Priorities for Adapting to Climate Change," contractor paper prepared for the Office of Technology Assessment, March 1992

react quickly and efficiently to trends deemed outside the range of normal, or will they assume that conditions-will return to historic norms? Will people overreact to periodic climate extremes that do not actually signal a substantial change in the underlying climate? Responses to recent extreme events, such as the Mississippi River flooding in the summer of 1993, may provide an interesting lesson.

CHOOSING ADAPTATION STRATEGIES

How should decisionmakers incorporate the uncertainties posed by a changing climate into long-term plans for resource systems? What can be done to minimize vulnerability to climate change? Uncertainty makes acting now difficult, but it also makes preparing for a wide range and intensity of climate impacts essential.

D. DOWNING © 1993



The Grand Teton National Park, along with other national parks and preserves, provides habitat for countless species of birds and wildlife. The parks and preserves also offer extensive recreational opportunities such as hiking, camping, nature study, and photography. These are examples of services at risk from climate change.

Possible responses to the threat of climate change depend on what one wants to **save.** Do we try to maintain systems in their current form (e.g., the extent of forests and the varieties of crops), or do we maintain the services they provide (e.g., enough food for the population, scenic views, beach recreation facilities)? Do we wish to minimize the economic costs of facing a changing climate? Do we attempt to forestall only catastrophic events? However these interests are balanced, two general primary characteristics of adaptation policies stand out: *flexibility* and *robustness*. By helping to ensure quick and effective response to changing circumstances (flexibility) and by being prepared for the worst (robustness), the potential costs of an uncertain future climate can be reduced.

Just how much effort should be expended to avoid future risks will ultimately depend on the perceived costs of the effort compared with the likelihood and scale of future damages that will be avoided. In some cases, the same strategies that help protect against climate risks might also provide some immediate and certain benefits: enhanced services from natural systems, improved productivity in managed systems, better means for dealing with existing climate variability and weather extremes, or reduced environmental damages from managed systems. The costs of these *low-regrets* strategies or activities may be relatively easy to defend. Other activities, however, would be most useful only in the event of severe climate change. The costs of such activities may be considered in the same light in which we consider the purchase of insurance-it may be better to pay a relatively small premium now than to be uninsured against the threat of severe and more costly ecological and economic damage.

Enhancing Flexibility

Any policies that improve the chances of adapting more smoothly and painlessly provide a buffer against the negative impacts of climate change. Flexible systems and policies are those that allow self-adjustments or midcourse corrections as needed without major economic or social disruption. For example, flexible systems can be fine-tuned to cope with hot and dry weather as well as more-intense rainstorms. The system should work now, under current climate conditions. Flexibility would not preclude potentially desirable actions or lock policy makers into expensive, irreversible decisions. For example, in some cases, building a dam is a less flexible policy than is water conservation. If new information becomes available that suggests that the dam is not needed in that location or is the wrong size, fine-tuning is difficult. Efforts to conserve water can (within limits) be used to supply quantities of water without building new, expensive infrastructure with 50- to 100-year lifetimes; the policy is also reversible in times when water is plentiful (see vol. 1, boxes 5-G, 5-H, 5-I, and 5-J).

Advancing the knowledge base will enhance flexibility. In agriculture, the development of new crops suited to a wide variety of climates, improved understanding of the performance of crops under a changing climate, and continuing education and extension programs to provide better-informed decisionmaking by farmers will all help smooth the path of adaptation (see vol. 1, ch. 6). In general, research that clarifies how systems respond to climate change will help identify and expand the range of possible adaptive actions and will speed their successful implementation.

Removing legislative or administrative constraints that now limit our ability to change would also promote flexibility. For example, the complicated programs of price supports in agriculture now penalize farmers who choose to change planting or management practices significantly. Given the importance of agriculture in the United States, large economic costs could be associated with even brief delays in agricultural adjustment to a changing climate. Other subsidies, such as those for irrigation and those implicit in the support for infrastructure in coastal zones, add to our inflexibility by encouraging the development of built systems in areas that maybe increasingly at risk to natural disasters. Resolving conflicts over the use of natural resources, through the creation of organizational structures or market incentives, should also help with our ability to implement change.

■ Enhancing Robustness

Policies can also minimize the risk of adverse effects from climate change by making systems less sensitive to climate. Robust systems are those that can tolerate a wide range of climate conditions and are, therefore, less vulnerable to climate change extremes. Actions that increase robustness in a system are those that help protect against the threat of large-scale losses or climate surprises. The robustness of a system can be increased in several ways. One is to take actions that make the system itself inherently more tolerant of a variety of climate conditions. For example, developing and planting crops that perform reasonably well under a wide range of climates may be wise no matter how the climate changes. Adding capacity to dams or other structures can make them more ‘‘robust, that is, able to accommodate greater variability in precipitation. Another way to increase robustness is to put a variety of mechanisms in place to protect against possible losses, hoping that some mechanisms will succeed even if others fail. For example, a mix of management strategies for forests and natural areas could be used to protect against climate change.

Improving the robustness of a system will often require an *insurance strategy-something* must be initiated now in order to avoid extremely high costs under a much warmer climate. The idea is that paying a small amount now will reduce the risks of a major loss in the future. For example, establishing gene banks or learning how to undertake ecosystem restoration may be an “investment” that would reduce the risks of catastrophic forest or ecosystem loss in the future.

Efforts that enhance the general health, productivity, or quality of a system can also enhance robustness by making the system more resilient, or able to tolerate some climate-related stresses. Actions promoting robustness include improving the quality and protection of wetlands, minimizing existing threats to natural areas, and establishing new preserves (see vol. 2, chs. 4 and 5). Planning and management measures that avert trends that make adaptation more difficult in the future are also robust strategies.

It is not immediately obvious that natural systems, such as forests or wetlands, are less robust (more vulnerable) in the short term than are managed systems such as agriculture and water-supply systems. Natural systems do have some inherent buffering to protect themselves against existing climate variability. However, what may put natural systems at greater risk than systems that are actively managed is continued stress from climate change over a long time period. Once a natural system declines, it may take many years to recover. Of particular concern is the possibility that losses to natural systems may be irreversible, such as the loss of species. In managed systems, it is much more likely that there would be intervention to reduce the losses because the economic value at stake is often very high.

Applying the Criteria

Federal agencies are currently making many decisions about the management of natural resources that could be significantly affected by climate change. What the Federal Government decides now about the management of water supplies, forests, wetlands, fish, wildlife, and other issues could limit or foreclose the ability of these resources and their managers to adapt to the future effects of climate change, or could help make us better prepared to deal with an uncertain climate future.

Given the broad criteria of flexibility and robustness, we identified a large class of policy options that could remove inefficiencies, address existing problems, and help insure against the uncertainties posed by climate change to resource systems. Many studies term such options no *regrets* or low *regrets* because they make sense to pursue now, even assuming no climate change. The question that arises is: Why are actions that are supposed to be prudent, anyway, even without the added impetus of climate change, being pursued in such a limited way (5)? Actions that appear reasonable for protecting resources cannot be considered in a vacuum. In reality, there are barriers of many sorts-in information, institutions, and process--even 10 options that appear to be low regrets. OTA's policy analysis focused on these barriers and tried to identify ways to overcome them.

Another large class of policy options calls for us to be prepared for the worst. Whether these options will still be seen as no-regrets once climate does change may depend on the rapidity and magnitude of that climate change, and the future response of decisionmakers. If, in the face of signficant climate change, the no-regrets options prove inadequate, there could indeed be regrets that substantially more aggressive measures were not taken earlier. OTA has also looked at some of the more aggressive measures that would be appropriate if the likelihood of climate change is considered high.

The policy options presented in this report to enhance the flexibility and robustness of the various resource systems represent a gradation from ''learn more about the natural resource system" to "improve the technology or know-how required for adaptation" to "relax the institutional constraints that tend to inhibit the ability or incentive to respond. " This gradation depends on whether the ability to respond to climate change is limited by information, by available technologies, or by the institutions that govern the system.

Coastal systems and water resources (discussed in vol. 1, chs. 4 and 5, respectively) face many institutional factors that may limit adaptation. Theoretically, there is enough water to supply needs throughout the United States, even under climate change. We know how to move water from one place to another and have technologies to save water or even to make fresh water from salt water. However, the complex system of water rights, lack of incentives to conserve water, and limits on the transferability of water result in daunting institutional constraints and inflexibility. In coastal systems, the infrastructure of roads and bridges and subsidized flood insurance encourage a degree of development in high-risk zones that maybe economically unwise even under current climate conditions and sea levels.

In agriculture, market incentives and annual planting cycles make the system quite responsive, or flexible, to change. As long as there are continued efforts in research, technology, and innovation that expand the base on which adaptation can proceed, coping with climate change should be relatively easy for agriculture--barring catastrophic changes (vol. 1, ch. 6). Yet, whether adaptation is optimal may depend greatly on our ability to remove certain institutional incentives that may encourage uneconomic farming of areas where climatic risks are high. In this regard, farm subsidies and disaster-assistance programs need review and, likely, adjustment.

For less-managed systems, our ability to facilitate natural adaptation is limited by inadequate information or understanding of natural processes and by the narrow range of available and suitable technologies for adaptation. In wetlands (vol. 2, ch. 4), sea level rise and changes in the timing and amount of precipitation will exacerbate ongoing habitat loss. Efforts to reduce current loss will make the system more robust and improve chances for adaptation to climate change. Actions to minimize the possibility of irreversible damage should receive high priority. For forests and natural preserves (vol. 2, chs. 5 and 6), climate change may make the continued existence of unique assemblages of plants and animals questionable. Natural areas have become the repository of biodiversity in the United States. Yet little is known about maintainingg, changing, restoring, or transplanting natural ecosystems. There is no systematic effort to document what is currently preserved and how that can be augmented or protected under climate change, Enhancing these areas through strategic acquisitions of land or land easements and through innovative coordination of management with adjacent landowners offers great promise as an approach for maximizing protection of biodiversity. Filling in gaps in our knowledge through research would allow us to better manage and protect these areas and to reduce the risk of decline under climate change.

OVERARCHING POLICY THEMES

As we developed and evaluated policy options, using the criteria described above, for the six different resource sectors examined in this report, many sector-specific policy options appeared to coalesce into several broad themes, or problems. Four particular themes were found to be shared by several or all of the sectors:

- geographic and institutional fragmentation,
- inadequate *communication of climate risk,*
- the need for *contingency planning,* and
- an ongoing Federal research effort-the U.S. Global Change Research Program--that will not fill many key *research and information gaps.*

Each chapter addresses these themes within the context of the appropriate resource sector, but the common threads are highlighted here. Below, we describe the overarching themes more fully and illustrate some possible directions Congress could take to begin addressing these broader policy challenges. Box 1-C examines some specific options from the resource chapters, and relates them to these common themes.

▮ Fragmentation

A key problem in natural resource management is that the most sensible management units from a resource perspective—watersheds or ecosystems—rarely correspond to the boundaries within which resources are actually managed. Furthermore, resources are usually owned and managed for multiple purposes. Many different government agencies and private owners may have some responsibility for the management of a given resource, with differing incentives motivating its management and use. As a result, resources may be fragmented geographically and jurisdictionally.

One aspect of fragmentation is the geographical division of landscapes and ecosystems that results from uncoordinated development and the encroachment of human activity. Such activity has left few ecosystems intact in the lower 48 States (the Greater Yellowstone Ecosystem is often cited as the most important remaining example). In most parts of the country, remaining natural areas have become ‘‘islands’ of habitat, surrounded by developed or altered landscapes and vulnerable to a variety of human stresses (see vol. 2, box 5-E). This fragmentation of former large ecosystems has led to greater stress on the natural resources within the remaining fragments. Many natural areas, including the federally pro-

Box 1-C--Solutions from General to Specific: Addressing the Overarching Problems

During the course of developing policy options for coping with climate change, OTA heard **repeatedly** from many experts that climate change alone is not necessarily the most worrisome threat to natural resources. Rather, climate change is likely to exacerbate various trends and problems that already plague natural resource management. Current management policies and practices for coasts, water resources, agriculture, wetlands, natural areas, and forests are perceived in many quarters as being inadequate in ways that not only hinder management today, but could impose greater constraints under a changing climate. Four particular problems were found to be common to several or all of the sectors: 1) Institutional and geographical fragmentation; 2) inadequate communication of information that would improve response to climatic risks; 3) **lack of contingency planning and, other measures to prepare for extreme events or weather** surprises; and 4) information gaps in various key scientific and policy areas.

Addressing these overarching problems will pose numerous challenges for **Congress and Federal agendas. All four problems have been recognized to varying degrees in the past, but progress toward solving them has been slow. Attempting to solve any of them could require far-reaching policy changes, but small piecemeal actions could be undertaken for individual** resource sectors by **many different government** agencies or by congressional appropriations, legislation, and oversight committees. Big, **bold policy changes could accomplish the job more** uniformly or effectively, but reaching agreement on solutions and then garnering sufficient support to implement them could prove impossible. Incremental changes do not require such widespread support and may accomplish specific goals, but such policies can also detract from needed larger changes by leaving the impression that no further action is necessary.

In the resource and research chapters of this report (vols. 1 and 2, ohs. 3 through 6), we suggest numerous policy options that address parts of the four overarching problems in waysthat are specific to each resource sector. In many cases these resource-specific options could be formulated in broader terms to attempt across-the-board solutions to the overarching problems identified above. Furthermore, many of the sector-specific options are interconnected, and could be more effective if enacted in a coordinated way. In some cases, any of several different resource-specific policy options could form a first step toward solving an overarching problem. A few of these options are described below.

Fragmentation

Options to help reduce Institutional fragmentation include:

- Promoting the reestablishment and strengthening of Federal-State river basin commissions to improve coordination among agencies. (Vol. 1, option 5-11 -''Wade")")
- promoting integrated resource management at the watershed level. (Vol. 2, option 4-22--''Wetland.")
- Creating a Federal coordinating council for ecosystem management. (Vol. 2, option 5-12-'' Preserves.")
- Amending the Science Policy Act of 1976 (P.L. 94-262) to strengthen the ability of the Office of Science and Technology Policy (OSTP) and the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET) to coordinate research and ecosystem management across agencies. (Vols. 1 and 2, option 3-1—''Research.")

Although these options seem varied, all four address, in some way, the problem of institutional fragmentation and the need for greater coordination and integrated management. If enacted individually, these policies could focus on specific problems in the management of water resources, wetlands, and preserves. However, any of the four could also serve as part of a larger effort to coordinate the management of all three retirees. Reinstated river basin commissions could form a local base for watershed management that **could be broadened to** include attention to wetlands and other natural areas within the watershed. Similarly, a Federal coordinating council for ecosystem management could use watershed units as one level of coordination **and** examine the interaction of water resources with other natural resources in that unit. The problem in trying to expand any of these individual options to cover the overarching concerns would be in how best to assign authority and enforcement capabilities for any coordinating agency without interfering with the jurisdiction of the agencies to be coordinated.

Options to help reduce **geographic fragmentation** include:

- Identifying and assigning priorities to the wetlands that are most important to protect and restore. (Vol. 2, option 4-19--''Wetlands.")
- Directing agencies to **modify their criteria for land acquisition** to include underrepresented ecosystems and long-term survivability. (Vol. 2, option 5-9--''Preserves.")
- Using current conservation incentive programs administered by the Secretaries of Agriculture and Interior to enhance the Federal effort to protect natural areas. (Vol. 2, option 5-10-'' Preserve")")
- Protecting highly valued forest sites. (Vol. 2, option 6-4--''Forests.")
- Providing incentives to reduce fragmentation of private forestland. (Vol. 2, option 6-5--''Forests.")

Several of the policy options for wetlands, preserves, and forests either explicitly address the problem of geographic fragmentation or could be used to do so. The options listed above would promote priority setting for land acquisition or restoration of valuable natural areas, including wetlands, forests, and other types of preserves. Reducing landscape fragmentation could be viewed as a high-priority goal. Furthermore, existing conservation incentive programs of various types could be required to focus on the lands most valuable for preventing or ameliorating fragmentation.

Communication of climate risk

Options to communicate risk through modifying subsidies include:

- Raising premium rates for the National Flood Insurance Program (NFIP) policyholders who receive subsidized flood insurance. (Vol. 1, option 4-1-''Coasts.")
- Reducing the Federal share of public disaster assistance. (Vol. 1, option 4-7–-"Coasts.")
- Reforming pricing in Federal water projects. (Vol. 1, option 5-5--''Water.")
- Defining disasters formally, with assistance provided only for unusual losses. (Vol. 1, option 6-3--''Agriculture.")
- improving participation in the crop-insurance program. (Vol. 1, option 6-5-''Agricuitur")")
- Eliminating incentives to destroy wetlands. (Vol. 2, option 4-8--''Wetlands.")
- Reducing Federal subsidies, such as Coastal Zone Management funds and flood insurance, in areas that have not established setback or "planned retreat" policies. (Vol. 2, option 4-16--' 'Wetlands.")

One of the major ways the Federal Government affects the responsiveness to climate risk is in the distribution of public money for disaster assistance and insurance subsidies. Subsidized and regulated prices distort the perception of changing risks and could slow the response to growing water scarcity and to increases in the frequency of droughts, floods, and storms. The options listed above suggest that policies to reduce or eliminate such subsidies could be beneficial in encouraging greater precautions and faster responses to changing climate risk in nearly every individual resource sector-as well as in reducing Federal spending in an era of constrained budgets. If enacted together, these options could go **a** long way toward addressing the overarching problem of misperception of risk.

Options to communicate risk through tax signals include:

- Eliminating or reducing tax benefits for coastal development (such as the casualty-loss deduction). (Vol. 1, option 4-16—''Coasts.")
- Reforming tax provisions to promote conservation investments. (Vol. 1, option 5-4--''Water.")
- Using current conservation incentive programs administered by the Secretaries of Agriculture and interior to enhance the Federal effort to protect natural areas. (Vol. 2, option 5-9--'' Preserves.")

(Continued on next page)

Box 1-C--Solutions from General to Specific: Addressing the Overarching Problems--(Continued)

The U.S. Tax Code can provide both incentives and disincentives for financial risks. Tax incentives can be used to encourage behavior that might reduce risks to humans and the environment, including investments in water conservation and **in protecting natural areas.** Tax **disincentives could be used to help prevent unproductive behavior, such as coastal development in high-risk zones or where development leads to the destruction of** wetlands or creates barriers against their movement inland as the sea level rises.

Other options to communicate risk include:

- Improving the research and extension process (develop a database on successful practices; expand farmer involvement; provide support for on-farm experimentation). (Vol. 1, **option 6-11 -''Agriculture.")**
- **Incorporating climate change scenarios into** forest plans and assessments, (Vol. 2, option 6-11--"Forests.")
- Eliminating the even-flow-harvest requirement of the National Forest Management Act (P.L. 94-588), which falsely implies that future timber supplies will be stable). (Vol. 2, option 6-12--"Forests.")
- **Incorporating sea level rise into National Flood Insurance Program mapping. (Vol.** 2, option 4-5--"Coasts.")

The Government is the source of considerable information that can serve to improve private sector response to a changing climate. Outreach and extension services will be valuable in communicating changes in the effectiveness of farm management techniques and crop choices, speeding the process of adaptation. Inventories, monitoring, climate data, and resource--status assessments will indicate trends in natural resource conditions **and** signal changes in the future supply of products and service from natural resource systems. **Better understanding of these** trends will help businesses and individuals to anticipate and adjust more effectively to **changing future** conditions. **Inappropriate signals about climate risk that create an unrealistic expectation of stable conditions may encourage** unwise financial investments in resource-dependent communitiesthat are at risk of decline. The pubic generally is not well-informed about the risks associated with living in coastal areas, and this lack of awareness has led and will continue to lead to large public and private expenditures. Educating people now about the risk of a rising sea level could greatly reduce future damages.

Contingency planning

Options to formalize contingency planning include:

- Creating an interagency drought task force to develop a national drought policy and plan. (Vol. 1, **option** 5-16--''Water.")
- **Creating a national flood-assessment board, (Vol. 1, option 5-17--''Water.")**
- **Establishing criteria for intervention in order to protect or restore forest health through a forest health bill. (Vol. 2, option 6-7--"Forests.")**

Droughts, forest fires, floods, and hurricanes have all become the focus of public attention in recent years after events such as the nationwide drought in 1988, the 5-year California drought of 1988-1992, the Mississippi floods in the summer of 1993, and Hurricanes Hugo and Andrew in 1988 and 1992. in many cases, contingency plans set up to deal with such disasters were either inadequate or nonexistent. Policy options for water resources and forests suggest different types of contingency **planning** that may help address future disasters as the climate changes. Because the presence of forests and wetlands moderates how water moves through the landscape, both should be considered in flood planning and development.

Options **that add a measure of "insurance" against catastrophic events include:**

- Increasing support for the development of new commercial crops. **(Vol. 1, option 6-14--"Agriculture.")**
- Conducting research on natural resources to prepare for climate change (restoration ecology, preservation of biodiversity, effective preserve design). (Vol. 2, option 5-2--''Preserves.")
- Directing agencies to modify their criteria for land acquisition to include underrepresented ecosystems and brig-term survivability. (Vol. 2, option 5-9--'' Preserves.")

- Enhancing forest seed banks and genetics research programs. (Vol. 2, option 6-1--"Forests.")

Preparing for extreme future climate conditions through the development of technologies or institutions will assist **in recovery** and can help reduce the threat of future damage. The development of crops well-suited to **harsher future climate may** provide some insurance against a steep decline in our agricultural sector. Contingency preparations for forests and preserves must consider the potential need for active restoration or protection if natural processes become excessively disturbed. Seed banks may provide the material to rebuild a forest in the event of severe decline and loss of spades or populations from their natural range.

Information gaps

Options to help decrease these gaps include:

- Supporting long-term research and monitoring on the *impacts* of climate change on wetlands. (Vol. 2, ***option*** 4-24--"Wetlands.")
- Increasing funding for ecological research in the U.S. Global Change Research Program (USGCRP). (Vol. 2, **option 5-1—"Preserves.")**
- Supporting coordinated research in federally protected natural areas. (Vol. 2, option 5-4--"Preserves.")
- Creating a national program for inventorying and monitoring. (Vol. 2, option 5-5-"Preserves.")
- Using the Experimental Forests for research on adaptation to climate change. (Vol. 2, option 6-2—"Forests.")
- Using existing monitoring and inventorying efforts to identify causes and effects of forest decline. (Vol. 2,option 6-6--"Forests.")
- Creating an Integrated Assessment program within or outside USGCRP positioned above the agency level. (Vols. 1 and 2, option 3-8--" Research.")
- Creating an adaptation and mitigation research program either within USGCRP or separate but parallel to it. (Vols. 1 and 2, option 3-5--"Research.")

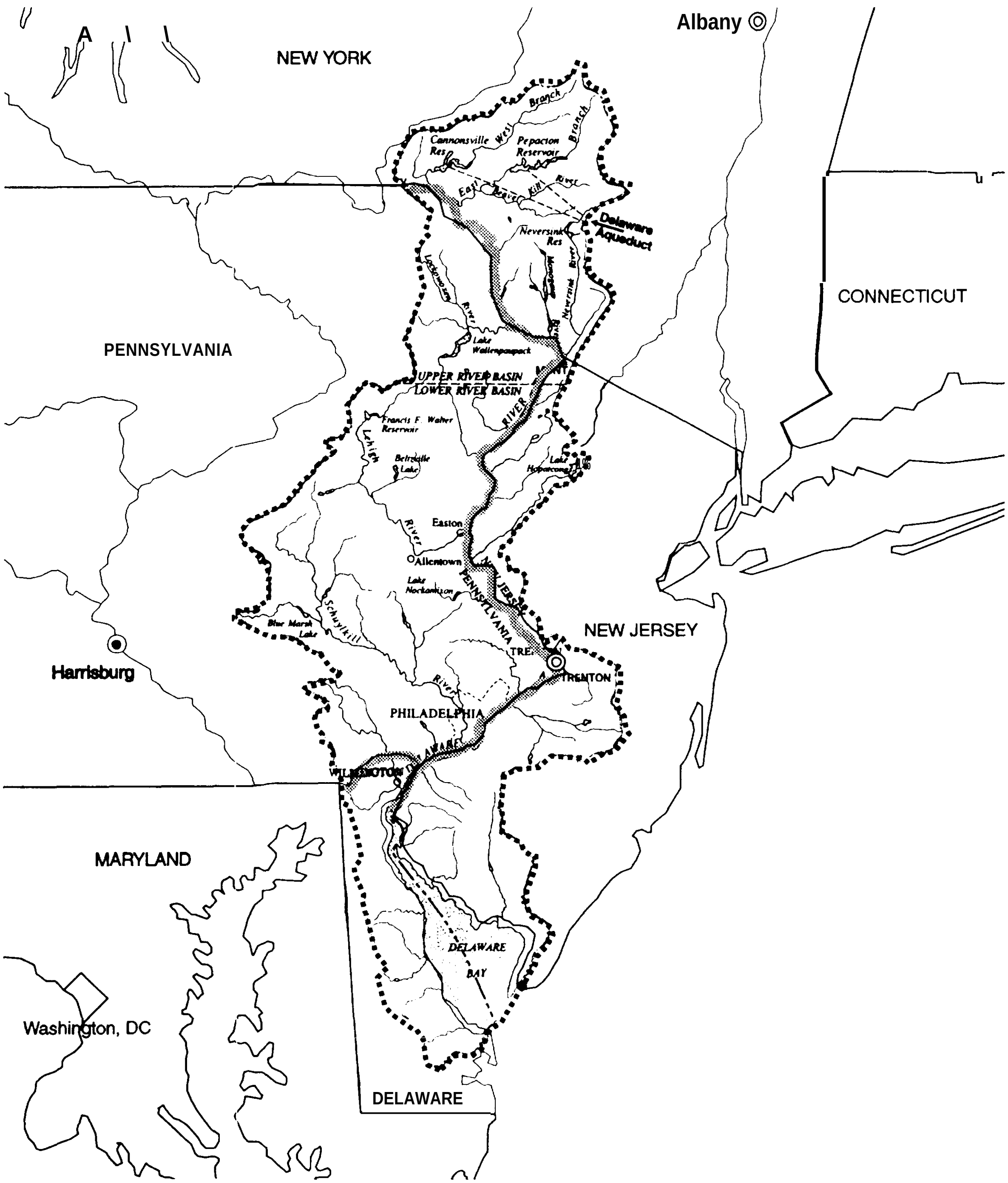
Many policy options suggest particular research questions or promote the use of specific existing programs to address some of the information gaps regarding climate change. Coordinating these different research efforts **and** ensuring that each considers some of the related concerns of others might yield synergistic results. For example, while the Experimental Forests should be useful sites for examining how forests ***may*** adapt to climate change, research could be focused more broadly to consider issues that affect natural areas (including questions of how to maintain biodiversity and how to restore damaged ecosystems) and forested wetlands.

While these research programs in individual areas are forming useful building blocks toward solving the overarching problem of lack of knowledge, a broader program of coordinated research across-the-board could also be attempted. Some of the research listed could be coordinated under the Ecological Systems and Processes priority group in the USGCRP. However, the USGCRP goals and purview need to be broadened to include ecosystem research, adaptation and mitigation research, and an iterative integrated assessment in order to be more useful to policy-making.

tected natural areas, may not be large enough to withstand future stresses such as climate change. Managing smaller areas as individual parcels in an uncoordinated manner and without larger needs in mind has become part of the problem.

A second aspect of fragmentation is the inefficiency that results from a lack of coordination in management across government agencies. It is not uncommon in even relatively small watersheds, for example, for dozens of Federal, State, and local agencies to share jurisdiction overwater and other natural resources. For instance, the Delaware River Basin is divided among four States (fig. 1-3). Responsibility for water resources alone in this basin is divided among at least 10 agencies in each of the four States and among more than 20 Federal agencies. In most basins, responsibility for groundwater manage-

Figure 1-3-The Delaware River Basin



NOTE: As is typical of many watersheds, the boundaries of the Delaware River Basin do not coincide with legislated boundaries. The multiple jurisdictions make management more difficult.

SOURCE: W.E. Harkness, H.F. Lins, and W.M. Alley, "Drought in the Delaware River Basin, 1984-85," in: *National Water Summary 1985—Hydrological Events and Surface Water Resources*, U.S. Geological Survey Water Supply Paper 2300 (Washington, DC: U.S. Government Printing Office, 1986).

ment is separate from that for surface-water management (see also vol. 1, box 5-D). Water quality and water quantity are usually treated separately. And jurisdiction over navigation, recreation, flood control, and wetlands may also be split, although all these aspects of water resource management are related and may affect one another. Problems are encountered in managing a single reservoir as if its operation does not affect how others within a basin are operated, or in managing to control floods without considering the role of wetlands. The result of this jurisdictional fragmentation is often seen in conflicting efforts, high management costs, and foregone opportunities to provide better overall service. These inefficiencies may be of increasing concern if climate changes threaten the supply and services of natural resources. Box 1-D describes the complexities of trying to manage a growing urban center, agricultural areas, and the Everglades of South Florida (see also vol. 1, box 5-B).

More effective management for coping with current and potential future stresses on natural resources and built systems is possible and needed. Today's agency-by-agency, owner-by-owner, and system-by-system management approach leaves much to be desired. Many improvements can be made by going beyond our customary fragmented style of management to consider more comprehensively the services of watersheds, ecosystems, and landscapes (see vol. 2, box 5-F). Within most sectors or systems examined in this report, we have identified options that can begin moving toward more integrated management and reduced geographical fragmentation: breaking down institutional barriers among agencies, acquiring and consolidating natural areas, and providing private owners with incentives to maintain the environmental services of a landscape. Regional priorities could be used to direct activities in regulatory, acquisition, and incentive programs. We also consider some more fundamental changes, such as creating major new programs and reorganizing agency responsibilities, which can be pursued if the political will exists. However, neither breaking down institutional barriers nor altering private incentives will be easy. Watershed management, for example, has been discussed for many years, but established styles of management have changed little to date. Nevertheless, watershed management seems to be a concept whose time has come: the Environmental Protection Agency (EPA), backed by the current Administration, has strongly advocated the approach, and watershed management is being considered in current legislation to reauthorize the Clean Water Act (P.L. 92-500) (see vol. 1, box 5-c).

More integrated planning and management along watershed and ecosystem lines is likely to be one of the best ways for the Nation to promote the flexibility, robustness, and efficiency that is desirable in coping with the uncertain impacts of climate change.

Communication of Climate Risk

If climate changes as predicted, resource managers and individuals will find it necessary to adjust to new circumstances. Certain parts of the country are likely to become much less desirable

NOAA

Hurricanes and other tropical storms cause millions of dollars' worth of damage each year as homes, boats, and businesses are destroyed by high winds and water. Some Federal programs and regulations encourage redevelopment in high-risk areas without requiring appropriate safety measures.

places to live and work. Even where climate changes are less harsh., current management practices and lifestyles may not continue to be appropriate. The speed with which resource managers and individuals can recognize and respond effectively to new climate conditions will largely determine the economic and social costs of climate change. Adaptation to change is likely to be delayed by the inherent difficulties in recognizing climate change against the background of normal climate variability. Responsiveness to changing climate risks may be further impeded by existing Federal programs designed to protect individuals from the financial risks of climatic extremes. It maybe enhanced by providing information about the nature of climate change risks, the changing resource situation, and the likely success of particular adjustments in resource-management techniques. Effective communication of the nature of climate-related risks can be promoted through formal educational efforts or through appropriate incentives.

The Government could better communicate climate risk by reducing the various public subsidies for developments in areas of high risk. The public has come to depend heavily on government disaster assistance and subsidized insurance programs, which helps reduce exposure to the financial risks from climate extremes. Such programs have been valuable in allowing the productive use of resources in areas of highly variable climate. Problems may arise, however, if the financial buffer provided by these Federal programs unintentionally encourages people to move into environments where they may be exposed to greater risk in the future, or reduces incentives to take adequate precautions against climate risk. Because development decisions are not easily reversible, and the consequences of decisions taken now are, in some cases, likely to be with us for many decades, it seems prudent to begin reexamining policies that may encourage development in climate-sensitive areas. Private citizens should recognize the true costs of extending farms into economically marginal areas, building structures in areas of high forest-fire risk, or locating buildings in coastal erosion zones.

We assessed two systems in which a reexamination of current risk protection policies may be especially important in the face of climate change: coastal areas and agriculture (see vol. 1, chs. 4 and 6). Flooding and erosion are of particular concern in coastal areas, and these hazards could increase in a warmer climate. We discuss options in the coastal and agriculture chapters that could help owners respond more effectively to climate change and that would decrease potential future exposure to climate risk. For example, the National Flood Insurance Program has been only partially successful in reducing the need for taxpayer-funded disaster assistance and in encouraging local mitigation efforts. In agriculture, Federal Crop Insurance, various disaster-assistance programs, and irrigation subsidies all tend to distort the manner in which farmers respond to climate risks. (See box 1-Eon water allocation in the Sacramento-San Joaquin River System and box 1-F on agriculture in the prairie-pothole region.) Improvements can and should be made in these program to ensure that in the future, individuals, communities, and the Federal Government are not exposed to excessive costs.

Equally important may be quickly communicating the detection of any change in key climate variables and other information that will assist in the responses to changing climates. Farmers and foresters, for example, may be reluctant to alter practices until they are convinced climate has actually changed. The potential role of the Extension Services in tracking the changing success of farming and forestry practices and spreading this information to managers may prove important in reducing the costs of adaptation.

Contingency Planning

The goal of contingency planning is to minimize losses from natural disasters or accidents by preparing in advance to take appropriate actions.

Contingency planning is important where the threat of significant losses is high in the absence of preparation and prompt response-as is the case with floods, forest fires, droughts, and hurricanes (see vol. 1, chs. 4 and 5 and box 4-C; vol. 2, box 5-I). Climate change could affect the intensity or number of extreme climate events, making preparedness perhaps even more important than it is now. However, adequate contingency plans do not exist for all parts of the country that are vulnerable to extreme events. For example, only 23 States have drought-management plans (197). The States that do have them, however, have generally adapted better to droughts than those without plans (197). We identified options that could help mitigate damages, including the ecological harm caused by natural disasters. Improvements in contingency planning would be helpful both to minimize near-term damages and to prepare for potentially greater damages caused by climate change.

States have a key role in planning for most extreme events and must continue to do so. States should be encouraged to develop contingency plans or to refine them with climate change in mind. The Federal Government also has a role in planning for natural disasters, with many agencies involved in some way in this activity (see cartoon on page 34). However, the Federal Government could do better at defining the respective roles of the agencies that have responsibilities for extreme events. It could also promote stronger coordination among Federal agencies and among the various levels of government in establishing requirements for assistance and in providing such assistance in a more timely, consistent, and equitable manner.

Contingency planning is also important when emergency measures are likely to be controversial; it allows potential responses to be considered in advance when there can be rational debate. Such controversies are very likely to be associated with any efforts to restore the health of natural ecosystems that have been severely harmed by climate-related stresses. This is well-illustrated by difficulties now faced in responding to "massively destructive forest health problems" in the Blue Mountain forests of Eastern Oregon (176; see vol. 2, ch. 6 and box 6-E). Although there is general agreement that major changes in management are needed in those forests, the response has been slow, and agreement about how to proceed has been hard to achieve. Procedures for responding to ecosystem health emergencies should be established.

Research and Information Gaps

The individual resource chapters outline the important research gaps that need to be addressed for coasts, water resources, agriculture, wetlands, preserves, and forests. Overall, we found that various strategies for coping with climate change can be identified for managed natural-resource-based *systems* (including the coastal zone, water resources, and agriculture--see vol. 1, chs. 4-6). Some of these strategies may require continued support for research on new technologies or management practices that will enhance the potential for adaptation. For natural systems, however (e.g., wetlands, unmanaged forests, and nature preserves-see vol. 2, chs. 4-6), the informational gaps in our understanding of these systems are so large that realistic response strategies are difficult or impossible to identify now (see also vol. 2, box 5-K).

Although an estimated $900 million is spent annually on what can be considered research in ''environmental life sciences' (54) or ''environmental biology,"[6] there is currently very little research directed specifically at protecting natural areas under climate change and helping land managers modify management strategies to re-

6 J. Gosz, Executive Secretary, Subcommittee on Environmental Biology, Committee on Life Sciences and Health, Federal Coordinating Council for Science, Engineering, and Technology, personal communication, Sept. 14, 1993. Only 11 percent of these expenditures overlaps with the Federal Global Change Research Program budget.

Box 1-D--Climate Change, South Florida, and the Everglades

Lying dose to sea level and in the preferred path of a sizable percentage of Atlantic hurricanes, South Florida is potentiality one of the most vulnerable areas of the United States to climate change. it is also one of the moat distinctive. South Florida's famed Everglades, a vast subtropical wetland of which about one-seventh is preserved in Everglades National Park, is seen by many as one of the crown jewels of the U.S. National Park System. Miami, Palm Beach, and other coastal communities in South Florida makeup one of the most popular seaside vacation destinations in the world. Despite hurricane and flood hazards,these cities have experienced phenomenal growth in recent years. In addition, varieties of crops can be grown in the warm, subtropical climate that grow nowhere else in the United States. And Miami has become a gateway between North and South America, transforming South Florida into an important international crossroads.

Despite, or perhaps because of, its distinctiveness and popularity, South Florida is under stress and, like a few other heavily developed parts of the United States, beginning to bump up against limits to growth. The critical factor is water. Although the region receives an annual average of 80 inches (152 centimeters) of rain, annual evaporation can sometimes exceed this amount and rainfall variability from year to year is quite high, resulting in periodic droughts and floods. In the past century, moreover, South Florida has been transformed from a virtual wilderness into a complex, interconnected system of developed and undeveloped land. The main elements of this system-the growing urban sector, agricultural areas, and the Everglades and other remaining natural areas--must all compete for the limited supply of water, and the competition is increasing with every new resident.

Much of the growth of South Florida has occurred since 1870. Then, fewer than 100 people lived in what are now Dade, Broward, and Palm Beach Counties. Now, about 5.2 million people occupy the same area The vast unaltered Everglades, which originally extended from Lake Okeechobee to Florida Bay, were seen by early settlers as hostile to human welfare and completely without value. Encouraged by a grant from the U.S. Congress, the State of Florida began draining these "useless" wetlands for agriculture, and by the earty 20th century, the natural character of the Everglades had begun to change. Farmers planted sugar cane and a variety of vegetables in the drained area south of Lake Okeechobee now known as the Everglades Agricultural Area (EAA).

The initial drainage system worked well enough during normal years but was stressed during occasional abnormal events and failed completely during a major hurricane in 1928. At that time, 2,000 people died in the EAA when the protective dike around Lake Okeechobee burst. This incident prompted the Initiation of a massive public works project, as attention shifted from drainage of wetlands to flood control. Eventually, an 85-mile (137-kilometer)[1] earthen dike was built around Lake Okeechobee, and the meandering 98-mile Kissimmee River, which fed the lake from the north, was transformed into a canal 48 miles long and 33 feet (10 meters) deep. Flooding problems diminished, but the former broad, riverlike system north of Everglades National Park has been greatly altered into a series of canals and pools. The former sheet-like flow of water to the park, necessary to its health, has been blocked. Today, the area has more than 1,395 miles of canals and levees and 143 water-control structures.

Projects to expand the supply of water to growing urban centers proceeded in tandem with flood-control projects. To accommodate demands for agricultural and urban expansion, diking and draining of wetlands continued, and as the expansion progressed, more water was diverted for these purposes. Today, additional water is diverted for sewage dilution, pest control, and frost protection. Some water is used to recharge aquifers that supply cities east of the Everglades and the populated areas of the Florida Keys. Large quantities of water that could be recycled or used to recharge urban aquifers are dumped into the Atlantic Ocean (see vol. 1, oh. 5, and vol. 2, oh. 4, for complete discussions of water and wetland issues).

A major effect of this decades-long restructuring of the natural hydrological system has been to drastically reduce the supply of water from the Kissimmee River watershed that reaches the much-diminished-in-size

1 To convert miles to kilometers, multiply by 1.609.

Everglades. The natural system has suffered in several ways as a result: 1) the abundance of species characteristic of Everglades habitats (e.g., wood storks, white ibis, tri-colored herons, and snowy egrets) has declined dramatically in the past 50 years, 2) more than a dozen native species have been listed as endangered or threatened (e.g., the Florida panther, snail kite, Cape Sable seaside sparrow, American alligator, and American crocodile), 3) nonnative and nuisance species have invaded the area (e.g., Melaleuca quinquinervia and the Brazilian pepper tree), 4) sizable land subsidence and water-level declines have occurred throughout the region, 5) water quality has been degraded by agricultural runoff containing excessive nutrients, such as phosphorus, 6) saltwater intrusion of coastal aquifers has occurred, 7) vulnerabilitytofire has increased, and 8) massive algal blooms have appeared in Florida Bay, accompanied by die-offs of shrimp, lobster, sponge beds, and many fish.

The impacts of development have not been limited to natural areas. As water use in the region has grown, susceptibility to periodic droughts has increased. A 1981 drought, for example, led to mandatory water restrictions for half the counties of South Florida and water rationing in the EAA. Pollution from cities, as well as from agricultural areas, has added to water-quality problems. Saltwater intrusion threatens aquifers used for urban water supplies.

Everglades National Park was created in 1947, the culmination of efforts that began in the 1920s. The transition of the Everglades from being perceived as ‘Worthless land” to an important preserve worthy of designation as an International Biosphere Reserve and World Heritage Site took decades, but preservation of this area and restoration of other degraded wetlands are now considered high priority by a broad spectrum of people and organizations. Although there is broad agreement that the hydrology of the Everglades should be restored to a pattern similar to that found in the original system, it will not be easy to balance the needs of the Everglades for water with the similar needs of other users.

South Florida’s Everglades and coastal areas, clearly already under stress, face an unusually difficult problem in the light of global climate change. Both are already vulnerable to sea level rise and intense tropical storms (see vol. 1, ch. 4). (Damage from Hurricane Andrew, for example, was not confined to urban areas--coastal mangrove forests were heavily damaged, as were trees in many densely forested hammocks.) Climate change could increase the current vulnerability to these events. Climate change may also result in a hotter and drier climate for South Florida, although predictions from general circulation models (GCMs) are not consistent on this point. Whatever occurs, the future is likely to be increasingly stressful for South Florida. Cities are likely to continue to grow and will almost certainty be protected from sea level rise, but the expense of protecting them could be immense. The Everglades, once deemed worthless, is now considered a valuable natural resource. As valuable as it is, however, the Everglades will probably not receive the same attention as cities threatened by rising seas will. Farmers are likely to resist attempts to hinder or reduce long-established patterns of agriculture in favor of other uses for water. In short, South Florida is a system increasingly “close to the edge.” The flexibility to satisfy **competing** interests for water and land has been reduced by actions taken since the turn of the century, and climate change may further reduce flexibility.

in recent years, some efforts have been made to offset some of the damage to the Everglades and restore some of the Iost flexibility to the natural system. In 1970, for example, Congress directed that not less than 315,000 acre-feet (389 million cubic meters) of water be delivered annually to Everglades National Park. In 1989, Congress enacted the Everglades National Park Protection and Expansion Act (P.L. 101-229), one purpose of which was to enable more natural flow of water through a portion of the park. More recently, the Federal Government sued the Florida Department of Environmental Regulation for not upholding its own water-quality laws, thereby allowing degradation of the Everglades to continue. As a result, the State has agreed to design and construct treatment areas in the EAA where drainage could be filtered before it is discharged to the park. The State has also directed the South Florida Water Management District to implement an Everglades Surface Water Improvement and Management Plan. Finally, as authorized in the 1992 Water Resources Development Act (P.L. 101-640), the US. Army Corps of Engineers will soon begin a long-term project to restore the Kissimmee River to an approximation

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Box 1-D--Climate Change, South Florida, and the Everglades--(Continued)

of its original meandering route, thereby increasing wetlands north of Lake Okeechobee, helping to improve water quality in the lake, and increasing the water-storage capacity of the entire Everglades system.

Although important steps are being taken to restore the Everglades, some major obstacles are stymieing the more comprehensive ecosystem plating that will be required to address the full range of South Florida's current and climate-change-related problems. One of the most vexing, and one encountered many times In OTA's study, is the lack of coordination among the responsible State and Federal agencies. Part of the problem is a result of a lack of shared values among agencies and among the constituencies they represent. Furthermore, each agency has a different mandate, and agencies' jurisdictional boundaries seldom coincide with boundaries of natural systems. One might expect that the preservation mandate of the U.S. Fish and Wildlife Service and the Florida Department of Environmental Regulation would often dash with the flood-control mandate of the Corps of Engineers and with the interests of EAA farmers, and such has been the case in South Florida. However, lack of coordination has extended even to agencies with similar mandates; a prominent example has been the difficulty of reconciling the National Park Service's ecosystem-wide approach to restoring the Everglades with the Fish and Wildlife Service's mandate under the Endangered Species Act (P.L. 100-707) to focus on protection of individual species.

Recently, Interior Secretary Bruce Babbitt expressed a strong interest in Everglades National Park and has made dear his intention to get the National Park Service and the Fish and Wildlife Service to work more closely together to develop a common policy. Babbitt has also announced plans to form a Federal taskforce in an attempt to overcome some of the coordination problems.

The broader challenge for the region is to manage this complex system in an integrated fashion to maximize the health of all its diverse elements. This is no small challenge because it may be very difficult to sustain agriculture without environmental costs, for example, or for urban areas to continue to grow indefinitely without some restraints. The effort to sort through these problems must take place with some understanding of what climate change may mean.

SOURCES: S. Light, L. Gunderson, and C. Holling, "The Everglades: Evolution of Management in a Turbulent Ecosystem," University of Florida, Arthur C. Marshall Laboratory, unpublished manuscript, 1993; National Audubon Society, *Report of the Advisory Panel on the Everglades and Endangered Species*(New York: National Audubon Society, 1992);J. de Golia, Everglades: The Story Behind the Scenery (Las Vegas, NV: KC Publications, Inc., 1978); K. Kemezis, "BabbittToTest Ecosystem Policy in the Everglades,"Environment Week, Feb. 25, 1993.

spend to climate change. In 1992, only $8 million was spent on research focused on adaptation to climate change.[7]

The U.S. Global Change Research Program (USGCRP) is a $1.4 billion research program. However, as currently designed, it will not provide either the practical technologies that might make us more prepared for climate change or the ecological information that would be helpful in providing policy guidance and adaptation options for natural systems. Overall, USGCRP is more focused on understanding the causes for and rates of climate change[8] than on examining the ecological and human impacts of change (see ch. 3 for a more complete explanation of USGCRP). The agencies primarily responsible

[7] The Working Group on Mitigation and Adaptation Research Strategies (disbanded in 1992) of the Committee on Earth and Environmental Sciences of FCCSET identified Federal research that focuses on or contributes to adaptation to global change (24).

[8] USGCRP is designed to produce a predictive understanding of the Earth system and focuses on three interrelated streams of activity: documenting global change (observations), enhancing understanding of key processes (process research), and predicting global and regional environmental change (integrated modeling and prediction). For FY 1994, a fourth activity stream, assessment, was added.

Box l-E–Water Allocation and the Sacramento-San Joaquin River System

The complexity and divisiveness of western water problems--and the potential for climate change to exacerbate those problems-is well-illustrated in the continuing battle over allocation of water in California The Sacramento-San Joaquin River System, and especially the Delta area where the two rivers come together in Northern California is the focal point of this conflict. Before western water development began, about 40 percent of California's runoff converged into the Sacramento-San Joaquin Delta on its way to San Francisco Bay and, eventually, the Pacific Ocean. However, about half of this water is now diverted to Southern California, the San Joaquin Valley, and parts of the Bay Area via the massive State Water Project (SWP) and Central Valley Project (CVP). The water delivered through these huge "plumbing" systems has enabled California's semiarid Central Valley to become one of the Nation's prime agricultural areas and has been partly responsible for the phenomenal population growth of Southern California's mild coastal areas.

Agriculture is now firmly established in the Central Valley, and about 16 million people-over 70 percent of the State's population—now live in Southern California. Water supply is crucial to California: it has been the basis for most agricultural, industrial, and economic development However, the transfer of water from Northern to Southern California has not come without a cost to the river system and the State. Water supply and allocation issues directly conflict with water-qualityand ecosystem concerns, and they pit interests of southern Californians against those of Northern Californians. Three issues are of special concern.

Delta fisheries-The Delta and extended Sacramento-San Joaquin River System provide important habitat for over 40 species of fish. Coho and chinook salmon, steelhead trout, and striped bass all reside in the river system **atone point** in their lives and have been especially important to the recreational and commercial fishing industries. Yet these species of fish have declined 50 percent or more since the early 1960s. Fewer than 500 winter run salmon have returned to spawn each year in the Upper Sacramento in recent years, compared with the 60,000 per year that returned 20 years ago. Only 432 steelhead returned in 1966 compared with over 17,000 in 1967 (16). The Delta smelt is dose to extinction. Causes of these dramatic declines include loss of habitat; water pollution; dam, levee, and diversion-facility obstructions; and drought. When conditions are poor in the Delta--when flows are low and water temperatures and exports are high-losses of young, ocean-bound salmon can be very high.

Fishermen, as well as fish, have suffered. Fish losses have cost the local economy over $15 million per year **in recent years. In effect, the** benefits to people who receive water diverted from the **Delta have come partially at the expense of both fish and fishing** interests. In March 1993, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service invoked the Endangered Species Act (P.L. 100-707) to protect winter run chinook salmon and Delta smelt, setting limits on the operations of the Central Valley Project and intensifying a dispute between State and Federal officials on how best to protect the Delta.

Delta farmland and levees-The Delta, once a natural marshland, was developed for farming around the turn of the century and now contains almost 550,000 acres (223,000 hectares)[1] of rich farmland. The marshland was converted to a mosaic of over 70 islands by building over 1,100 miles (1 ,800 kilometers)[2] of levees. The levee system is fragile, however. The peat soils of the Delta have been gradually compacting, requiring that levees constantly be raised or repaired. Many of the levee-surrounded Delta islands are now well below sea level. Maintenance of the levee system is important for protecting life, property, and infrastructure from flooding on Delta islands. Permanently flooded islands would also have major adverse effects on both water quality in the Delta and freshwater supplies. Since 1960,24 levees have failed, and with each year, the fate of these islands becomes more uncertain.

1 To convert acres to hectares, multiply by 0.405.

2 To convert miles to kilometers, multiply by 1.609.

(continued on next page)

Box 1-E--Water Allocation and the Sacramento-San Joaquin River System--(Continued)

Water quality--Water quality in the Delta is of concern because of possible salinity intrusion into the western Delta from San Francisco Bay, wastewater discharges that contain chemical pollutants, and the inflow of agricultural drainage water that may contain pesticide residues and other toxic agents (18). Maintaining water quality and ecological health in the Delta(by, among other things, ensuring that an adequate amount of fresh water reaches the Delta) is legally required by the State but may conflict with water transfers and local consumptive uses. This is especially true during drought, when there may not be enough water to fulfill all demands. Drought poses another problem as well: during low-flow periods, water temperature in system rivers increases, and this has contributed significantly to the decline of odd-water anadromous fish species in recent years.

In sum, Californians are making heavy demands on the Sacramento-San Joaquin River System. They recognize that the means of transferring water from the Delta must be improved to maintain water quality and to enable more efficient transfer of supplies to the southern part of the State, but the issue has proved to be one of the most controversial water problems in the West. In 1982, for example, California voters defeated a referendum to build the so-died Peripheral Canal around the Delta to improve the system's efficiency. Northern Californians overwhelmingly rejected the proposal, for fear that the Delta's environment would not be adequately protected and because they perceived that populous Southern California was attempting yet another "water grab." A/though there was more support in Southern California, many in that part of the State feared the project's high cost.

Studies of the potential impact of climate change in California suggest--but have by no means proven--that the regional effects of climate change could be reduced mountain snowpack, a shift in runoff patterns (i.e., in timing, amount, or duration of precipitation), and large decreases in summer soil moisture. Specifically, a possible result of warming temperatures is that more winter precipitation will fall as rain and a reduced mountain snowpack will start melting earlier in the spring. As a result, reservoirs would fill faster. Because a portion of reservoir space must be reserved for flood-control purposes, the additional water would have to be spilled. A/though California's total water budget might remain the same, less would be available during the summer, when water demand is highest The reduced snowpack in effect represents the loss of one or more storage reservoirs. Maintaining adequate freshwater flow to San Francisco Bay would be more difficult in summer and could increasingly conflict with water needed for consumptive purposes. Summer temperatures would also likely increase in the Sacramento and other rivers and represent a threat to fish.

A further complication could be sea level rise. The intergovernmental Panel on Climate Change predicts a total sea level rise of 28 inches (65 centimeters)[3] by 2100. Such a rise would inundate the entire Delta area and have devastating effects on Delta islands and water quality. A sea level rise of more than 2 feet would transform the current 100-year high-tide peak at Antioch, a western Delta location, into a 1 in 10 event--making such rare occurrences more common. Levees would be even more expensive, or even impossible, to maintain. Because the Delta islands are developed for farming and valued for helping preserve water quality, the initial response to incremental sea level rise is likely be to try to preserve the islands. In the long run, a phased retreat from the Delta may have to be considered (142). Choosing between preservation at any price and abandonment would not be easy.

If the above impacts occur (Or worse, if California's water budget actually decreases), maintaining California's water supplies for consumptive purposes and maintaining the health of the Delta will be a great challenge. This would be especially true during droughts, which, if more common than-and as extreme as--the current drought In California, could have devastating impacts. A suite of demand-and-supply management and supply-augmentation responses to the State's water problems is being considered. No one response will be sufficient Conservation and water marketing could significantly ease California's water problems, but building new reservoirs and even some desalination plants and other responses may be needed as well.

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3 To convert inches to centimeters, multiply by 2.540.

SOURCE: Office of Technology Assessment, 1993.

Box I-F-Changes in Agriculture and the Fate of Prairie Potholes: The Impacts of Drought and Climate Change

The prairies comprise millions of acres over a vast geographical area that includes parts of Canada, and the States of Montana, North Dakota, South Dakota, Minnesota, and lowa.The region is characterized by a glaciated, depressed topography with poorly defined drainage that results innumerous small lakes and wetlands known as prairie potholes.[1] Millions of potholes dot the landscape, providing an impermanent water source for the region's agricultural operations and diverse wildlife, including migratory waterfowl. Since the early 1960s, a general shift in the structure of the agricultural economy has occurred in the prairie region, involving a move toward more-intensive farming practices (60). The drainage of prairie potholes has been accelerated in order to bring more land into production and to increase yields on existing cropland. However, drought conditions in recent years have evoked concerns about the sustainability of the regional agriculture and wildlife and have raised questions about impacts that may result from climate change.

The drying effects of climate change are certain to affect the prairie-pothole region by altering aquatic conditions. Agricultural operations and wildlife rely on prairie potholes for water. An increase in temperature, which would influence aridity in continental interior areas, would reduce available volumes, thereby putting both farming and waterfowl at risk in addition to changes in the availability of surface water, water storage in the soil is likely to decrease (134). Temperature changes may also mean an extended growing season, which could alter the nesting and feeding habits of wildlife. in total, climate change will affect the region by increasing existing stress on the prairie-pothole ecosystems and agriculture.

Agriculture operations in the prairie region have long provided the bulk of the Nation's wheat supply. Wheat is well-suited to the region's dryland agriculture, with the majority of precipitation failing during the growing season and with relatively cool temperatures keeping evapotranspiration rates down. Farming in the region has become more and more intensive as agriculture has become increasingly mechanized. These developments have had a considerable effect on the fate of prairie potholes, which have decreased from 20 million to 7 million acres (8 to 3 million hectares)[2] leaving only 35 percent of the original pothole acreage intact (179). A poor farm economy in the 1980s coupled with mechanization caused prairie farmers to push every possible acre into production. North Dakota's potholes were being drained at an estimated rate of 20,000 acres per year to support conversion to agriculture (179). And drainage rates became similarly high in other prairie States, as farmers recognized the potential value of new farmland.

Now, although 20 percent of all remaining prairie potholes are protected,[3] prairie potholes are among the most threatened ecosystems in the United States. They provide prime nesting grounds and habitat for a multitude of waterfowl and other wildlife. Since the 1970s, populations of three common duck species (the mallard, the pintail, and the blue-winged teal) have declined dramatically. Populations of some other species of duck less dependent on potholes in agricultural regions have increased. The mallard, pintail, and blue-winged teal nest in the drought-prone zone of intensive agriculture (1 19). These migratory waterfowl have lost not only extensive areas of breeding habitat, but also adjacent vegetated areas once used for food and cover. Here,the detrimental effects of the loss of wetlands cleared for agricultural use are dramatic; wildlife populations have likely been cut in half (60).

1 Prarie-pothole wetlands are relatively shallow, water-holding depressions that vary in size, water permanence, and water chemistry.They are located in the glaciated Portion of the North American Great Plains and are the single most important breeding area for waterfowl on this continent (63). They also support a variety of other wildlife.

2 TO convert acres to hectares, multiply by 0.405.

3 Protection includes, but is not limited to: ownership by Federal or State governments,short- and long-term government easements, and ownership by private conservation groups.

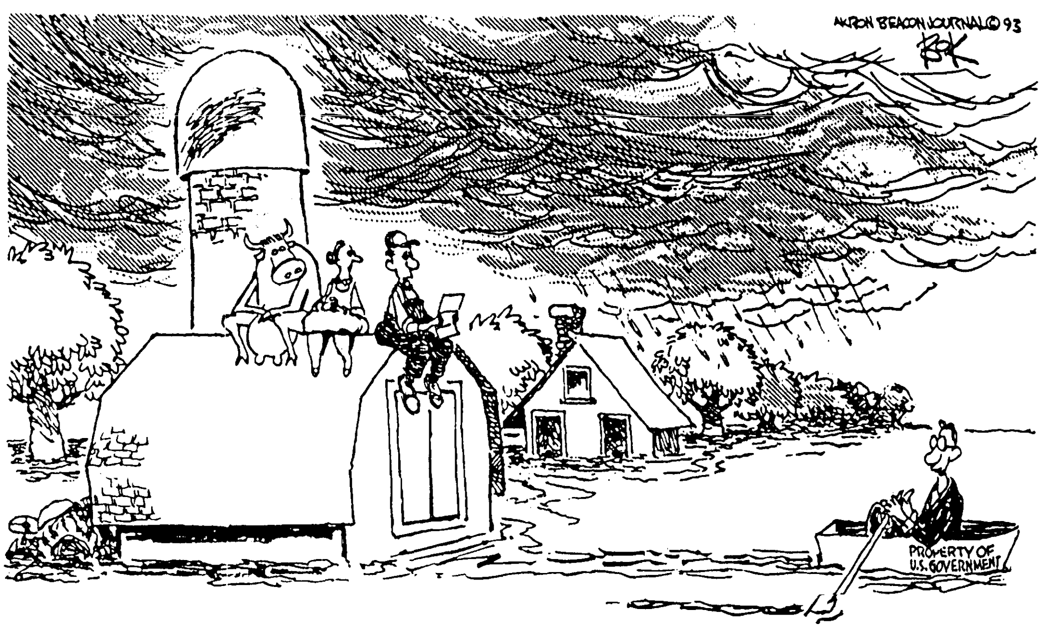
(Continued on next page)

Box 1-F--Changes in Agriculture and the Fate of Prairie Potholes The Impacts of Drought and Climate Change--(Continued)

Though these changes have been occurring over along period of time, effects were most dramatic during recent drought conditions in the region. Severe drought marked both the 1988 and the 1989 growing seasons in North Dakota, the heart of the country's spring wheat production area (143). This dry spell was the second to occur during the 1980s and the fourth serious drought in the past three decades (143). The lack of precipitation and subsequent loss of soil moisture resulted in dramatic decreases in agricultural yields and in abandonment of some cropland. Despite the grain crop losses (some more than 70 percent), net farm income and farmed acreage did not suffer. This was basically due to government drought assistance, in the form of insurance and direct aid The combination of insurance, aid, and the higher grain prices requiting from the drought helped farmers avoid losses that might ultimately have led to extensive farm failure and abandonment

Climate change may significantly alter growing conditions in the prairie region. Changes resulting from global warming may decrease both water depth and the number of ponds holding water in the spring and summer. This aspect is likely to further influence the degradation of waterfowl and wildlife habitat and to upset populations. Waterfowl may respond by migrating to other areas, relying heavily on the semipermanent prairie-pothole wetlands, remaining on permanent wetlands but not breeding, or failing to renest as they currently do during drought (160). On the other hand, drier conditions in these shallow, temporary, seasonal wetlands will make land-use conversion to agriculture much more reasonable in terms of expense and ease. Long-term changes in agricultural activityinthe region, caused by economics and climate change, are sure to affect the fate of prairie potholes and the waterfowl and wildlife they support, placing them at further risk.

SOURCE: Office of Technology Assessment, 1993.



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"LOOKS LIKE A DISASTER RELIEF CHECK, CROP LOSS COMPENSATION, AND A FINE FOR DISTURBING A WET LAND."

for research and management of public lands (the Department of the Interior (DOI), the U.S. Department of Agriculture, the National Science Foundation and EPA) combined receive less than 30 percent of the total funding for Ecological Systems and Dynamics (less than 5 percent of the total USGCRP budget). Given that such research on ecological and human impacts may take years or decades to produce results, the slow process may cost us the ability to respond to global change in areas that are especially at risk to irreversible damage. In addition to understanding climate impacts and effects, it is important to know how to minimize socioeconomic impacts. Ultimately, to be useful in planning for an uncertain climate, USGCRP must include ecosystem research that can feed into management, socioeconomic analysis, and adaptation research. An assessment process that incorporates all these categories and permits inputs from stakeholders and policy makers is necessary to make USGCRP truly policy relevant. This is a much broader definition of "assessment" than USGCRP can accommodate given its current research program and structure.

NEAR-TERM CONGRESSIONAL ACTION

In the resource chapters (vol. 1, chs. 4-6, and vol. 2, chs. 4-6) of this report, a series of ''fnst steps' is outlined to illustrate ways to begin incorporating climate change considerations into statutes, policies, and programs relating to various natural resources-coasts, water, agriculture, wetlands, preserved lands, and forests. The frost steps for the resource chapters are summarized briefly in the last section of this chapter. Several of the first steps focus on actions that offer important and immediate benefits, even without climate change as an additional factor justifying them. Several targets of opportunity in the near-term congressional agenda, in the announced and potential initiatives of the new Administration, and in the programs of the various agencies can be capitalized upon now.

Likewise, the USGRP offers annual opportunities for changes. Chapter 3 discusses several directions the program could take; many of these options are included below as possible near-term congressional actions. The process of policy development in government is not so orderly that one can lay out and follow a detailed plan of logical first steps, followed by logical second steps, and so on. Regular congressional reauthorization cycles for major natural resource programs, the annual budget cycle, election cycles, the fragmentation of responsibilities among congressional committees, and still other policy-making realities provide the context in which decisions about climate change will be made. Seen in this light, the choice of first steps is significantly influenced by an assessment of where the opportunities lie.

■ Annual Appropriations

Even if Congress did nothing else, each year it would enact legislation appropriating money for carrying out governmental programs. Thus, an immediate and recurrent annual opportunity to address many of the issues considered in this report is through the appropriation process. Most simply and directly, to narrow the breadth of uncertainties that exist today, Congress can ensure adequate levels of funding for existing climate-change-related research programs. Through the appropriation process, Congress can also encourage natural resource management agencies to carry out their monitoring and research programs in ways that meet their intended objectives while simultaneously producing data that could be useful to their own or other agencies' climate change research efforts.

The annual appropriation process is also the means by which Congress makes major long-term investments-for example, in land acquired for National Parks and wildlife refuges and in dams and other water resource projects. Until now, climate change considerations have not been a factor in deciding whether any of these investments were prudent. One could justify inclusion of such considerations now because climate change has the potential to lessen the value of such investments. Thus, Congress could require that the land-acquisition, water-resource-development, and other similar proposals brought before it be accompanied by explicit evaluations of how climate change may affect the long-term viability of the investment. Alternatively, in the case of lands proposed to be acquired for conservation purposes, Congress could direct that the criteria by which agencies rank their acquisition priorities include some consideration of potential climate change impacts on those lands or their resources. Building up the Nation's reserve of protected land would help stem some climate change impacts by reducing fragmentation and, possibly, reducing other threats to natural area resources. Increased protection and reduced fragmentation of these areas could help build more resiliency into some natural systems (see vol. 2, chs. 4 and 5).

Congress has increasingly linked policy direction to agency funding during the appropriation process. Congress could include requirements in its various appropriation bills that each of the agencies managing natural resources potentially affected by climate change provide Congress with its own evaluation of the agencies' preparedness to cope with a range of climate futures. The appropriation process may also be especially well-suited to encouraging agencies that implement climate-sensitive programs (e.g., agricultural disaster assistance, crop subsidies, and flood insurance) to develop long-term budget projections for those programs based on several future climate scenarios. In this way, a budget-conscious Congress can better inform itself early on about the potential costs of climate change for those programs.

Reauthorization Cycle

In addition to the annual appropriation cycle, congressional action is heavily influenced by the reauthorization cycles of major Federal programs. Congressional attention is not focused on all issues at once. Rather, at any given time, its attention is disproportionately focused, through its committees, on the major Federal programs for which current authorization is about to expire. The process of extending that authorization provides an opportunity to evaluate the workings of a program closely and to provide legislative direction for that program for a period of many years. Thus, at least with respect to changes in existing Federal natural resource programs, the best opportunities to implement the first steps recommended here are in the context of laws and programs that are about to be reauthorized.

Among these, the Clean Water Act is a high-priority target of opportunity (see vol. 1, box 5-C). Comprehensive revisions of that law have been proposed, and the act's wetland provisions are undergoing particular scrutiny. The reauthorization of the Clean Water Act provides a key opportunity to address one of the more important needs identified in this report-the need to achieve more effective integration of resource-management efforts across political jurisdictions. Comprehensive watershed planning (see vol. 1, ch. 5), which integrates wetland protection and restoration goals (see vol. 2, box 4-A), water-use-efficiency goals, strategies for controlling point-source and non-point-source pollution, and both water-quantity and water-quality concerns generally, could create the institutional capability and flexibility to anticipate and plan for climate change. Such planning could be especially valuable for finding creative ways to resolve current conflicts in which landowner and development interests chafe at restrictions on use of wetlands, while environmental interests decry the continued loss of wetlands (see vol. 2, ch. 4 and box 4-B).

Another major target of opportunity is the upcoming reauthorization of farm programs in the 1995 Farm Bill. The next reauthorization cycle could provide a forum for considering how to enhance farmers' flexibility and effectiveness in responding to a changing climate and how climate change may affect Federal expenditures on disaster assistance and farm commodity programs (see vol. 1, ch. 6).

■ New Targets of Opportunity

In addition to the reauthorization of existing laws, Congress regularly considers altogether new legislation creating programs for existing or new agencies of Government. A program of potentially great significance on the horizon is Interior Secretary Babbitt's proposal to create a National Biological Survey (see vol. 2, box 5-L). Legislation to establish the Survey has been introduced in both the House and Senate, and a National Research Council committee has been asked to offer advice on the formation and role of the Survey. The nature, mandate, resources, and overall purposes of the National Biological Survey, however, are still very much in the process of development. The bills introduced in Congress thus far to establish the Survey give only a very general description of its functions. Thus, there exists an opportunity to shape the content and direction of this new institution in ways that would be useful to the management of natural resource systems in a changing climate.

The rationale frequently offered by Secretary Babbitt for creating a National Biological Survey is its potential, by cataloging the biological resources of the Nation and monitoring their status and trends, to avert future ''train wrecks, ' that is, the disruptive and wrenching conflicts between conservation and development goals. A ''train wreck' of another sort could take the form of severe adverse impacts on our natural resources from climate change for which we were unprepared. A National Biological Survey could help detect, evaluate, and prepare for that climate change. Thus, an important opportunity exists to structure the mission and capabilities of the Survey so that it can contribute to the early detection of indicators of climate change, a better understanding of the ability of organisms and natural communities to respond to climate changes, and the design and management of a system of preserves best able to achieve the purposes for which they were established. Careful congressional attention now to these details in the design of a National Biological Survey could yield major returns in the future (see vol. 2, ch. 5).

■ Existing Statutory Language

Of the many Federal statutes pertaining to the management of the natural resource systems discussed in this report, only one-the Coastal Zone Management Act (CZMA; P.L. 92-583)--explicitly addresses climate change and its potential consequences. The 1990 amendments to that law required that possible sea level rise resulting from climate change be anticipated and addressed in State coastal zone management plans (see vol. 1, ch. 4). Congress could extend this legislative precedent to other statutory arenas; here, we attempt to identify which statutes may be most appropriate for this.

None of the statutes governing the various natural resource systems discussed throughout the full report precludes the agencies responsible for their management from fully considering climate change. Existing grants of authority are sufficiently general and open-ended to allow an agency, on its own initiative, to examine the implications of climate change for the natural resources under its jurisdiction and to tailor its management of those resources accordingly. The question, therefore, is whether Congress wishes to supplement the existing legislative framework with explicit directives pertaining to climate change.

Several categories of legislation may be especially appropriate for considering possible climate-change-related amendments. First among these are statutes, such as CZMA, that require long-range planning for the management of natural resources. For example, the Rangeland and Renewable Resources Planning Act of 1974 (RPA; P.L. 93-378) requires the preparation of a forest "resource planning assesment' that looks

50 years into the future. Similarly, the Clean Water Act requires preparation of area-wide waste treatment plans that look two decades into the future, a planning horizon also found in the Pacific Northwest Electric Power Planning and Conservation Act (P.L. %-501). In general, the longer the time frame over which management is to be planned, the greater the likelihood that climate change may affect the resources being managed. Thus, mechanisms to ensure that climate change is taken into account when long-range plans are being developed and to ensure that plans can be revised as new information about the direction and magnitude of climate change becomes available are clearly desirable.

A second statutory area, where it is especially important to ensure that potential climate change is considered is long-term public or private investments affecting natural resources. Examples include public land acquisition for parks, wildlife refuges, and the like (see vol. 2, box 5-C). Historically, such public land acquisitions have been viewed as permanent investments, with the intention of keeping the areas acquired in public ownership in perpetuity. The expectation implicitly accompanying these investments has been that the areas acquired would, with appropriate management, continue to provide the environmental and recreational benefits for which they were acquired indefinitely into the future. Climate change introduces a new uncertainty about the validity of this expectation. At the very least, it suggests the need for a more careful examination of whether particular acquisitions are, in fact, likely to continue to provide the environmental benefits that they provide today.

Somewhat similar are public or private investments in dams and other water-resource-development projects. Public projects are governed by the Water Resources Planning Act (P.L. 89-80) and private ones are licensed pursuant to the Federal Power Act (P.L. 102-486). The implicit assumption underlying both has always been that hydrological models based on past climate will accurately predict future conditions as well. The possibility of climate change casts doubt on the continuing validity of that assumption and may warrant statutory revisions explicitly requiring water resource planning agencies and Federal regulators to factor climate change into their decisionmaking.

A third statutory arena relevant here includes those laws that require an evacuation of the expected environmental impacts of planned actions. Foremost among these laws is the National Environmental Policy Act (NEPA; P.L. 91-190); similar, though less far-reaching, laws include the Fish and Wildlife Coordination Act (P.L. 85-624) and the Endangered Species Act (P.L. 100-707). Under these and similar laws, expectations of the environmental impacts of planned actions may vary, depending on whether a constant or changing climate is anticipated. Legislative direction could provide useful guidance to agencies with respect to their duties to consider climate change possibilities in implementing their responsibilities (see, for example, vol. 2, box 5-D).

A fourth set of laws that warrant discussion consists of those that authorize research programs. The Clean Water Act and the Rangeland and Renewable Resources Planning Act are examples. As this report makes abundantly clear, there are many uncertainties about climate change, including its magnitude, its direction, and its impact on natural resource systems. Natural resource management will require research aimed at resolving many of today's uncertainties. Reflecting that need in the legislative description of the various research missions may serve to underscore the importance of this area of inquiry. Each resource chapter highlights important research options to consider.

Finally, the Science Policy Act of 1976 (P.L. 94-282), which established the Office of Science and Technology Policy (OSTP) and the Federal Coordinating Council on Science, Engineering, and Technology (FCCSET), could be amended to strengthen the ability of these offices to coordinate science and ecosystem management across agencies.[9] These offices have the authority to develop and implement coherent, government-wide science policy and have been the mechanism for coordinating several multi-agency programs. However, OSTP has not always been an active or influential player in the executive branch, and FCCSET lacks the authority to set priorities, direct policy, and fully participate in the budget process (17, 51). FCCSET acts largely as a fulcrum for coordination. Agency participation in FCCSET projects is voluntary, and FCCSET has no authority over how participating agencies spend their funds. Congress could amend P.L. 94-282 to change this. Similarly, the U.S. Global Change Research Act of 1990 (P.L. 101-606) could be amended to require periodic integrated assessment reports to be presented to Congress and to specify key participants in the assessment process.

SUMMARIES AND FIRST STEPS FOR EACH RESOURCE CHAPTER

The Coastal Zone

The coastal zone is a complicated area that includes both human-made and relatively 'undisturbed" features, ranging from densely settled urban areas to cypress swamps (see vol. 1, ch. 4). Populations in coastal areas are growing faster than in any other region in the United States, and the construction of buildings and infrastructure to serve this growing population is proceeding rapidly. Consequently, protection against and recovery from hazards peculiar to the coastal zone, such as hurricanes and sea level rise, are becoming ever more costly (163). The combination of popularity and risk in coastal areas has important near-term consequences for the safety of coastal residents, the protection of property, the maintenance of local economies, and the preservation of remaining natural areas (see fig. 1-4).

The expected climate change impacts are likely to exacerbate problems that already plague the coastal zone (66). Sea level rise will substantially increase flooding and erosion in areas already vulnerable. Coastal storms-whether or not they increase in intensity or frequency under a changing climate-will have increasingly greater effects as sea level rises.

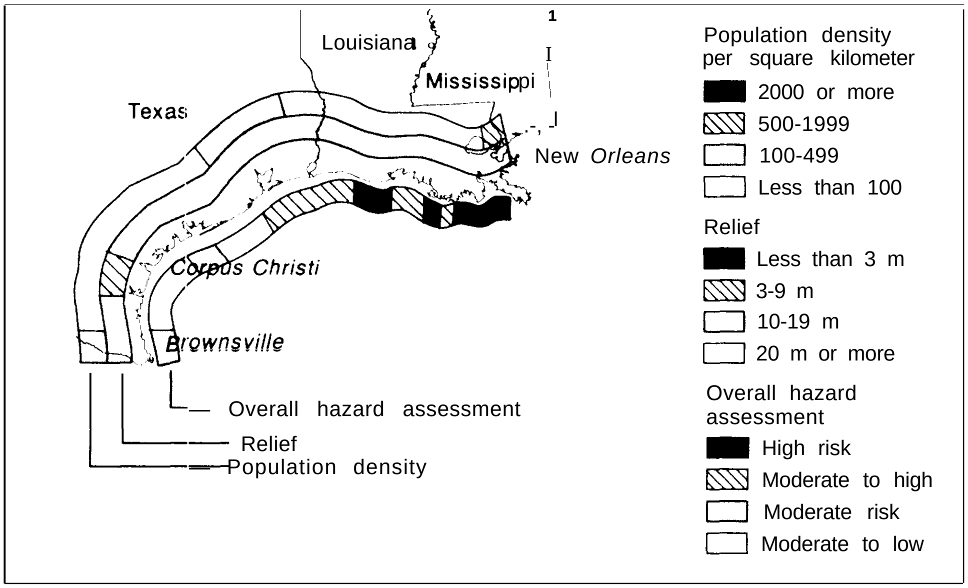
The coastal areas most vulnerable to the effects of climate change are those with low relief and easily eroded shorelines-such as those in the Southeast and Gulf Coasts-and those where the coastline is already subsiding, such as in Louisiana (52). Structures close to the ocean in low-lying areas are also vulnerable.

U.S. FISH AND WILDLIFE SERVICE

Barrier islands provide protection for coastal ecosystems and help stem erosion. In some cases, such as this barrier island near Tampa, Florida, these islands have been heavily developed, exposing many communities to the risks of serious damage from storms and high seas.

[9] OSTP was established to "define coherent approaches for applying science and technology to critical and emerging national and mternational problems and for promoting coordination of the scientific and technological responsibilities and programs of the Federal departments and agencies in the resolution of such problems," and FCCSET was established to ''provide more effective planning and administration of Federal scientific, engineering, and technological programs" (P.L. 94-282, the Science Policy Act of 1976).

Figure 1-4--An Assessment of Coastal Hazards: Texas and Louisiana



NOTE: To convert square kilometers to square miles, multiply by 0.624. To convert meters to feet, multiply by 3.260.

SOURCE: U.S. Geological Survey (USGS), "Coastal Hazards," in: National Atlas of the United States of America (Reston, VA: USGS, 1985).

Although development pressures in coastal areas are driven by many social and economic trends, government policies can influence the appropriateness, rate, quality, and location of development. The current system of allocating the costs of preventing or repairing climate-related damage in the coastal zone among Federal, State, and local governments and private entities encourages certain types of risky development, or at least does not discourage them (11). Climate change will likely add to the risks and costs of living in the coastal zone. It is essential that all stakeholders, such as property owners, understand them and that coastal development and preservation are guided by this understanding. The sooner policies are in place that encourage an adequate appreciation of risk, that offer sufficient incentives to take adequate precautions, and that attempt to overcome the organizational fragmentation that makes a unified approach to coastal climate change issues impossible, the easier and less costly adaptation to a changing climate is likely to be.

The Federal Government has an interest in promoting sound planning and public safety in an effective and efficient manner. Federal coastal zone policies can be improved in many ways to better guide the decisions of those living in coastal areas, and a suite of options for doing so is presented in volume 1, chapter 4. We focus on five general categories in that chapter: revamping the National Flood Insurance Program (NFIP), improving disaster-assistance policies, revising the Coastal Barrier Resources Act (P.L. 97-348) and the Coastal Zone Management Act, changing beach-renourishment guidelines, and altering the U.S. Tax Code.

To help focus on where to start with responses to climate change in the coastal zone, some first steps that could be taken are listed below.

- Revamp the National Flood Insurance Program. The National Flood Insurance Program could be revised to provide stronger incentives to reduce the potential costs associated with high-risk development in coastal areas. Congress has been considering revising the NFIP for several years, and bills to do this have been introduced in both the House and Senate. H.R. 62, the "National Flood Insurance Compliance, Mitigation, and Erosion Management Act of 1993," contains provisions that partially address some of the NFIP improvements that maybe desirable. Most pressing is the need to adequately address erosion along the coast. Erosion losses will increase with rising sea levels. The Federal Emergency Management Agency does not now have the authority to map erosion risks or to reflect such risks in insurance premiums, and as a consequence, information and incentives to avoid development in eroding areas are inadequate. Also, it seems especially desirable to increase insurance premiums after multiple claims are made on properties in high-risk areas subject to repeated flooding.
- Improve disaster assistance. Several bills have also been introduced in the 103d Congress to revise disaster-assistance policies and regulations. More stringent disaster mitigation by States and localities could be required, which could hold down future costs to the Federal Government. This could be accomplished by more strongly tying disaster assistance to adoption of mitigation measures. H.R. 935, the "Earthquake, Volcanic Eruption, and Hurricane Hazards Insurance Act of 1993, " for example, would establish minimum criteria for reducing losses, recommends such measures as fiscal incentives to reduce losses, provides for low-interest loans or grants to retrofit facilities vulnerable to hurricanes, and provides guidelines for establishing actuarial premium rates for disaster insurance. S. 995, the "Federal Disaster Preparedness and Response Act of 1993, ' would establish, among other things, a grant program and accompanying performance standards to help States prepare for, respond to, and recover from major disasters.
- Strengthen coastal zone management. The Coastal Zone Management Act will be up for reauthorization in 1995, and this provides an opportunity to require stronger State controls on risky development. Such controls could include, for example, an erosion-setback program (already adopted by several States), re-restrictions on construction of immovable buildings, a relocation-assistance program, restrictions on rebuilding damaged or destroyed structures in high-risk locations, and adoption of minimum coastal-construction standards. All of these controls would add some degree of protection against sea level rise and flood or storm damage. Another possibility for reducing risks of living on the coasts would be to encourage States to adopt coastal-hazards-management programs. These could be overseen jointly by the National Oceanic and Atmospheric Administration and the Federal Emergency Management Agency.
- Promote public education. The public generally is not well-informed about the risks associated with living in coastal areas, and this lack of awareness has led and will continue to lead to large public and private expenditures. H.R. 935 provides one possibility for expanding public education. The act authorizes education programs and provides funds to States to implement them through a self-sustaining mitigation fund. The private sector, particularly the private insurance industry, could also play an important role in increasing awareness of coastal hazards.
- Require increased State and local contributions to beach-nourishment operations.

Most benefits of the U.S. Army Corps of Engineer's beach nourishment and shoreline-protection projects are realized at the local or regional level, yet these projects are often heavily subsidized. In most instances, the Federal share is 65 percent. Greater State and local contributions could be required, both for initial construction and for maintenance, and Federal funding could be made conditional on adoption of stronger mitigation measures. These adjustments would tend to increase the interest of local governments in acting to limit community exposure to coastal hazards.

■ Water Resources

Many factors are straining the Nation's water resources and leading to increased competition among a wide variety of different uses and users of water (see vol. 1, ch. 5). Human demands for water are increasingly in conflict with the needs of natural ecosystems, and this has led to significant water-quality and water-quantity problems (see vol. 1, box 5-B). In addition, water infrastructure in many urban areas is aging.

Although it is unclear exactly how climate change will affect water resources, climate change has emerged as another important factor to consider in water resource planning. Changes in water availability as a result of climate change could further affect already overburdened systems, and changes could occur in the frequency, duration, and intensity of floods and droughts (105). The areas that are most vulnerable to climate change are, not surprisingly, places that are already experiencing stressed water resources (see fig. 1-5), such as many parts of the Southwest and South Florida; the central part of the country, which most models predict will become hotter and drier; and areas where competition for water is expected to increase.

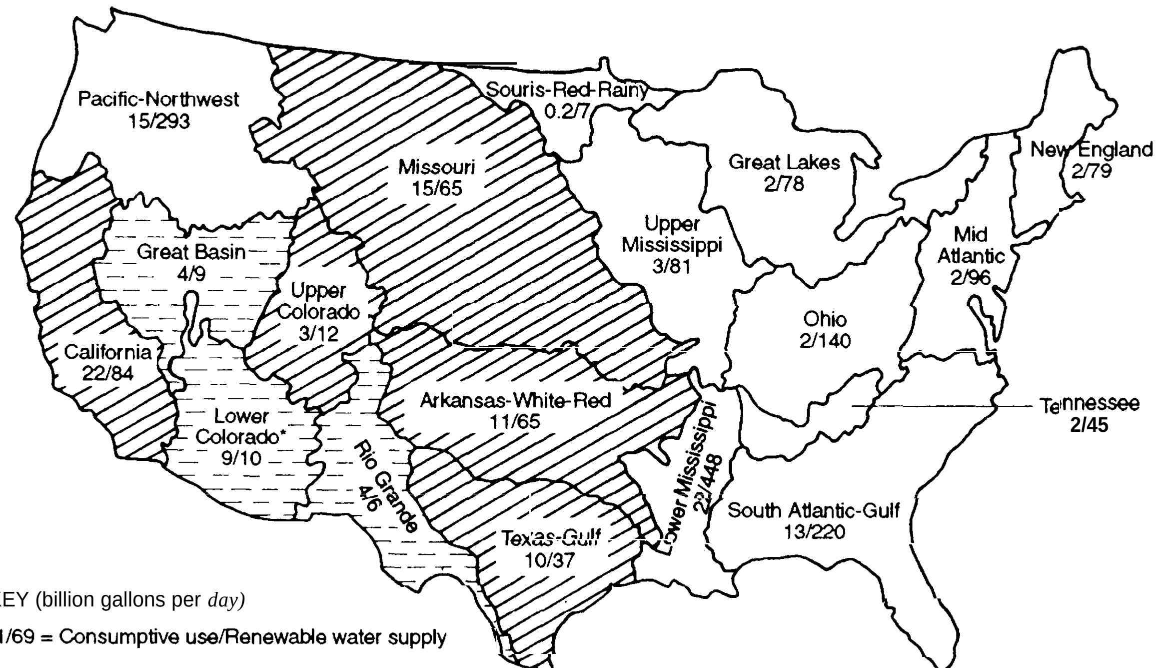
The country faces a huge challenge in adapting its water resource systems to the many current and potential stresses. The numerous impediments to this adaptation include the fact that traditional engineering solutions for developing additional water supplies-such as dam construction-have become prohibitively expensive and politically less acceptable because the best sites have already been developed. Federal agencies' responsibilities for water often overlap or conflict, and coordination among different levels of government on water issues is often inadequate (166) (see vol. 1, box 5-F). Many institutional arrangements for the management and allocation of water resources are rigid and inefficient, making them ill-equipped to cope well with water scarcity. And there are very few incentives to conserve water.

Water resource planning is a complex political, economic, sociological, scientific, and technological endeavor, so adaptation to change will not be straightforward. In encouraging adaptation to changes in water resources caused by climate change, the Federal Government, in cooperation with State and local agencies, should focus on encouraging five types of activity: improving demand management (e.g., through pricing reform and conservation); improving supply management (e.g., through improving coordination, jointly managing ground- and surface-water supplies, and improving the management of reservoirs and reservoir systems); facilitating water marketing and related types of water transfers; improving planning for floods and droughts; and promoting the use of new analytical tools that enable more efficient operations.

The following first steps toward improving water resources planning and management—selected from a longer suite of options presented in volume 1, chapter 5—are intended to both relieve existing stresses and make sense for climate change.

- Improve extreme-events management. Despite all efforts to date, both floods and droughts continue to cause significant losses to human and natural systems (143, 200). Greater coordination of the many agencies with flood- or drought-related re-

Figure 1-5-Water Withdrawals and Consumption **in the Coterminus United** States, **1985**



KEY (billion gallons per *day)*

11/69 = Consumptive use/Renewable water supply

Consumptive use as a percentage of renewable supply

0-10 10-40 40-100

NOTE: To convert gallons to liters, multiply by 3.785.

SOURCE: Adapted from W. Solley, R. Pierce, and H. Perlman, *Estimated Use of Water in the United States in 1990*, USGS Survey Circular 1081 Washington, DC: U.S. Geological Survey, 1993).

sponsibilities is needed. Congress could direct the executive branch to create high-level coordinating bodies, such as an inter-agency drought task force and a national flood-assessment board. Such bodies could be given the responsibility to develop a national drought policy and to establish national goals for floodplain management. The “National Flood Insurance Compliance, Mitigation, and Erosion Management Act of 1993” (H.R. 62) calls for establishment of a flood-insurance task force. This bill could also be broadened to create a more comprehensive flood-assessment board.

- Make it easier to manage reservoirs on a basin-wide level. Operating reservoirs within the same basin as a single system rather than individually (as is often the case) could greatly improve the efficiency and flexibility of water-quantity management. New legislation, perhaps as part of the next omnibus water bill, could grant the Army Corps of Engineers and the Department of the Interior’s Bureau of Reclamation greater flexibility to manage their reservoirs basin-wide and thus encourage development of a more integrated approach to waterquality, wetland, flood, and drought management.
- Support water marketing. As long as adequate attention is given to protecting all affected parties, water markets could provide an efficient and flexible way to adapt to various stresses, including a changing climate. It would be very useful for Congress to clarify reclamation law on trades and transfers and define the Federal

Government's interest in facilitating the creation of markets (193). Congress could urge the Department of the Interior to provide stronger leadership to assist with water transfers, and water marketing could be thoroughly evaluated as part of the Western Water Policy Review, authorized in late 1992.

- Promote the use of new analytical tools. Further development, dissemination, and use of new modeling and forecasting tools could greatly enhance water resource management. Some current analytical efforts have not been adequately funded, and the most advanced tools now available are not yet being used by many States or water utilities. Small investments in promoting dissemination and use of these tools today could save substantial sums later. Section 22 of the Water Resources Development Act of 1974 (P.L. 93-251) authorizes funding for training and technical assistance to States and could be used to promote the adoption of the new tools. Congress could also consider providing funds to develop or refine tools that incorporate climate uncertainty into traditional hydrologic analyses.
- Promote demand management. The upcoming reauthorization of the Clean Water Act is one potential target of opportunity for improving water-use efficiency (see vol. 1, box 5-C). Congress could consider making conservation projects eligible for the State revolving-fund loans created under the act to fund wastewater treatment plants. The Federal Government could set an example by adopting efficient water-use practices in its own facilities. The Energy Policy Act of 1992 (P.L. 102-486) requires that Federal facilities adopt conservation practices to the extent practicable, but it concentrates primarily on energy conservation. A technical-adjustment bill to the Energy Policy Act could be considered in the 103d Congress and would provide a way to clarify and underline congressional intent toward water conservation in Federal facilities.
- Expand the scope of the Western Water Policy Review. With the enactment of Title 30 of the Reclamation Projects Authorization and Adjustment Act of 1992 (P.L. 102-575), Congress authorized the President to oversee a major water-policy study. Title 30 directs the President to undertake a comprehensive review of Federal activities that affect the allocation and use of water resources in the 19 western States and to report findings to appropriate congressional committees by the end of October 1995 (190). Climate change is not mentioned as a factor motivating the Western Water Policy Review, but the study could provide an opportunity to assess more fully how climate change may affect water resources and to evaluate policy options that might help with adaptation to a warmer climate. Congress could expand the scope of the Review beyond the West, or it could authorize a similar follow-on study of eastern water issues. The Review could also provide an opportunity to explicitly consider land-use practices and water resource issues jointly. The relationship between the two is close, and there appear to be significant opportunities to improve both water-quantity and waterquality management by improving land-use practices.

Agriculture

Agriculture in the United States is an intensively managed, market-based natural resource. Throughout the world, agriculture has adapted continuously to the risks associated with normal climate variability, just as it has adapted to changes in economic conditions. The American agricultural sector will undoubtedly make further adaptations in response to climate changes, with market forces rewarding and encouraging the rapid spread of successful adaptation (30, 41, 148). Just what these adaptations will be and what public actions could be taken to encourage them are addressed in detail in volume 1, chapter 6, of this report.

The possible effects of climate change on agriculture are difficult to predict. Agricultural productivity is likely to be affected worldwide, which would lead to alterations in the regional distribution and intensity of farming (1, 188). The range over which major U.S. crops are planted could eventually shift hundreds of miles to the north (13, 150) (see vol. 1, box 6-C). For American farmers, already facing increasingly competitive and growing world markets, any relative decline in productivity compared with the rest of the world would mean lost markets (40). A significant warming and drying of the world's climate might lead to an overall decline in agricultural yields (75, 150). Consumers would bear much of the cost through higher food prices or scarcities. Some individual farmers might still benefit through locally improved yields or higher prices; others might suffer because of relatively severe local climate changes. Rapid geographical shifts in the agricultural land base could disrupt rural communities and their associated infrastructures.

If the United States wants to ensure its competitive position in the world market and meet the growing demands for food without higher prices, public efforts to support the continued growth in agricultural yields remains necessary. Climate change adds to the importance of efforts to improve the knowledge and skills of farmers, to remove impediments to farmer adaptability and innovation, and to expand the array of options available to farmers (157). Efforts to expand the diversity of crops and the array of farm technologies insure against a future in which existing crop varieties or farming systems fail (137) (see vol. 1, box 6-H). Efforts to enhance the adaptability of farmers-to speed the rate at which appropriate farming systems can be adopted-lower the potentially high costs of adjustment to climate change.

USDA AGRICULTURAL RESEARCH SERVICE

This soybean field shows the devastating effects of droughts. The farmer indicates how tall soybean plants would normally be. Warmer climates could lead to an increase in both number and severity of droughts.

Impediments to adjusting to climate change are numerous (see vol. 1, box 6-I). Water shortages will probably limit the potential for compensating adjustments in certain regions. The uncertainty of climate change makes effective response difficult, as do limitations on the availability of suitable crops and agricultural practices. The decline in the Federal Government's interest in agricultural research and extension is also a problem (138, 174); more-vibrant research and extension programs could enhance adaptability.

Certain agricultural programs may increase the costs associated with a changing climate (90). Because the commodity programs link support payment to maintaining production of a particular crop, they could inadvertently discourage adjustments in farming. Disaster-assistance programs may become increasingly costly under a harsher climate, and, if not well designed, may tend to discourage farmers from taking appropriate cautionary actions to reduce exposure to climate risks. Restriction on the marketing of conserved water may limit the incentive for efficient use of scarce water resources.

The most pressing tasks concerning agriculture and climate change that the Federal Government should undertake are: improving technology and information transfer to farmers in order to speed adaptation and innovation in farm practice; removing the impediments to adaptation created unnecessarily by features of commodity support and disaster-assistance programs; and supporting research and technology that will ensure that the agricultural sector can deal successfully with the various challenges of the next century.

The Government could organize its approach around the following first steps, which should increase the ability of the farm sector to adjust successfully to a changing climate.

- Revise the commodity support programs. Congress addresses farm issues every 5 years in omnibus farm bills, with the next one likely to be debated for passage in 1995. The annual budget-reconciliation process and agricultural appropriations bills offer intermediate opportunities for revisions in commodity support programs. Commodity support payments are linked to the continued production of a single crop. If a farmer significantly changes crops, support payments will be reduced. This link discourages the responsiveness of farmers to changing market and climate conditions. The cumulative economic costs of even temporary delays in adjusting to climate change might prove to be large. Congress should consider breaking the link between farm support and the production of a single crop. A further increase in flex acreage (an amount of land that can be shifted to new crops with little penalty) or other more substantial revisions in the commodity support programs that would allow greater flexibility in crop choice (42) could be considered in the 1995 reauthorization of the Farm Bill. These changes would increase the ability of farmers to adapt to climate change.
- Encourage research and development in computerized farm-management systems. The competitiveness of the farm sector will increasingly depend on advances that improve the efficiency of U.S. farmers-rather than on further increases in intensity of input use. Computerized farm-management systems include land-based or remote sensors, robotics and controls, image analysis, geographical information systems, and telecommunications linkages packaged into decision-support systems or embodied in intelligent farm equipment. Such systems will be increasingly important to the farmer's ability to increase yields, control costs, and respond to environmental concerns. The U.S. Department of Agriculture's Agricultural Research Service already provides leadership in this area and has proposed an ''Integrated Farm Management Systems Research' program that would provide for the development and broader use of technologies that have the potential to greatly enhance the efficiency of farming and to increase the flexibility with which farmers can respond to climate conditions.
- Use the 1995 Farm Bill to modify disaster-assistance programs. Since the late 1970s, Congress has been considering how to best structure the crop-insurance and disaster-payment programs (20, 21). After a flurry of proposals and studies before the passage of the 1990 Farm Bill, the programs were left essentially unchanged. Major revisions are likely to be considered in the 1995 Farm Bill. The best option for revising these programs remain unclear. For the purpose of preparing for climate change, any program that provides a greater incentive for farmers or local communities to reduce their exposure to risk should lessen the potential for large-scale future losses and encourage adaptation to changing climate risks. Features of a restructured system might include: defining disasters formally,

with assistance provided only for statistically unusual losses; eliminating either crop insurance or disaster payments (or merging the two programs) so that one does not undercut the incentives to participate in the other; limiting the number of times a farmer could collect disaster payments; and requiring farmers or farm communities to contribute to a disaster-payment fired, thus providing a greater incentive to reduce exposure to risks.

I Wetlands

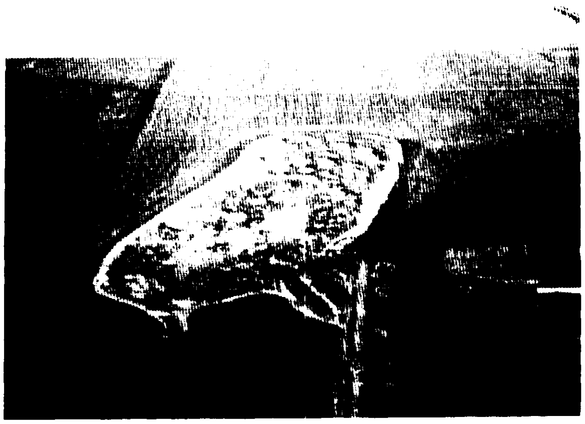
More than half of the Nation's wetlands have been destroyed by activities ranging from agriculture to flood-control projects to urban development. Roughly 5 percent of the lower 48 States is currently covered by wetlands (see vol. 2, ch. 4). They provide diverse products of considerable commercial value, playing a key role in the production of goods such as finish, shellfish, fur, waterfowl, timber, blueberries, cranberries, wild rice, and peat. Wetlands also nurture biological productivity, slow surface-water flows, and transform nutrients and toxic chemicals. Wetlands are key to the harvest of 75 percent of the Nation's fish and shellfish and harbor about one-third of the Nation's threatened and endangered species (83).

As a result, in 1989, the Federal Government embraced the policy goal of no net loss of wetlands-any destruction of wetlands should be offset by an equivalent restoration or creation of wetlands (28, 184). Steps to achieve this goal, however, have not been fully implemented. Part of the problem is that no single Federal statute is directed at protecting, restoring, and acquiring wetlands, and there is no coordinated effort to monitor and evaluate wetlands. Different authorities with different goals are scattered across many Federal and State agencies, and the criteria they use for decisionmaking are somewhat inconsistent. Federal policies have sometimes failed to discourage--and sometimes have encouraged— wetland destruction (179). Few programs for wetland acquisition and restoration address the possibility of climate-induced alteration of wetlands.

Climate change is likely to accelerate the loss of wetlands, especially of the following highly vulnerable types: coastal wetlands, depressional wetlands in arid areas (i.e., inland freshwater marshes and prairie potholes), riparian wetlands in the arid West and Southwest, and tundra wetlands. Coastal wetlands may be drowned by a rising sea or altered by changing salinity (123, 194, 198). Depressional wetlands are susceptible to the lowered water tables that will likely result from the higher temperatures, increased evaporation, and decreased summertime precipitation predicted for these already dry areas. Riparian wetlands in the arid West, which rely on water flowing through rivers and streams, could also be threatened by drier conditions. Tundra areas in Alaska may shrink as increased temperatures allow the permafrost to thaw and drain.

Whether or not a no-net-loss goal can be achieved as the effects of climate change become more pronounced, the goal remains a useful focal point for policy makers (1 14). Wetlands are a diminishing resource, and the Federal Government could play a lead role in ensuring that wetlands survive climate change by adopting the following objectives: protect existing wetlands, restore degraded or converted wetlands, facilitate migration (e.g., the upslope movement of coastal wetlands as sea level rises), and improve coordinated management and monitoring.

Given the available policy levers (regulation and acquisition, incentives and disincentives, and research), limited money to fired programs, and the level of scientific understanding of the impacts of climate change on wetlands, we identified the following strategies as first steps to use in responding to climate change and the threats it poses to wetlands. Additional options are assessed in volume 2, chapter 4.



Prairie potholes, like these in North Dakota, serve valuable storm-water-retention functions and provide breeding and stopover habitat for migratory waterfowl. Agricultural development, encouraged in part by Federal subsidies, has eliminated many of these wetland. Climate change may pose further risks if moisture declines or if farming intensifies with a warming in these northern lands.

- Revise the Clean Water Act. The act is up now for reauthorization, and it could be revised to improve wetland protection (169). This could be done through minor revisions or through transforming the act into a broad wetland-protection and watershed-management act. For example, the mitigation requirements could be clarified to ensure that lands set aside for protection or restoration more than compensate for wetlands that are destroyed. Congress could establish uniform standards for mitigation activities and require that restoration projects be monitored and evaluated for success in meeting these standards. At a broader level, Congress could devise a mechanism for coordinated management of water quality and wetland resources at a regional or watershed level. For example, regulations covering non-point-source water pollution might be linked to wetland protection, allowing wetland restoration or protection in exchange for relaxation in pollution-control requirements (127).
- Develop and implement a priority plan to coordinate wetland protection across agencies. Direct Federal agencies to develop and implement uniform regional plans guiding wetland protection, acquisition, mitigation, and restoration and to coordinate the designation of wetlands deemed high priority for protection or restoration. These priority plans could be built on existing plans under various agencies (e.g., the Army Corps of Engineers, the Environmental Protection Agency, DOI'S Fish and Wildlife Service, and the U.S. Department of Agriculture) that now set priorities for wetland management and acquisition. With better coordination and guidance and a watershed-management focus, existing programs could accomplish wetland protection more efficiently.
- Ensure that all Federal policies and incentives are consistent with wetland protection. Congress could ensure that all Federal policies and incentives are consistent with wetland protection, reviewing Federal programs to find and eliminate those that offer incentives to destroy wetlands and to perhaps bolster programs that encourage wetland protection. For example, the Coastal Barrier Resources Act (P.L. 97-348, as amended) might be extended to include coastal wetlands; funding for the Wetlands Reserve Program might be restored to at least authorized levels and targeted to wetlands in high-priority areas. The Fish and Wildlife Service could be required to complete and issue the report on the impact of Federal programs on wetlands that was mandated in the Emergency Wetlands Resources Act of 1986 (P.L. 99-645).
- Conduct research, development, monitoring, and evaluation in key areas. A new National Biological Survey at the Department of the Interior could incorporate wetland monitoring as part of its mission (see vol. 2, ch. 5). Relevant agencies should be encouraged to include wetland research in

their component of the U.S. Global Change Research Program (USGCRP).

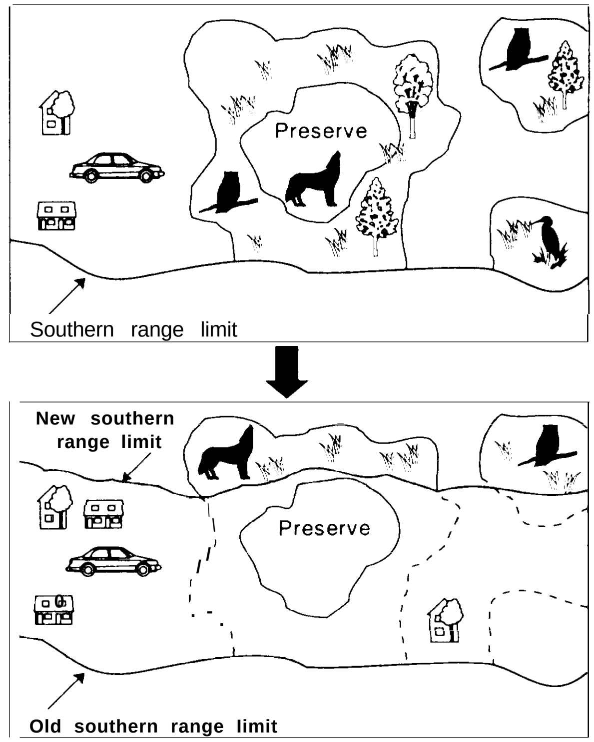
Federally Protected Natural Areas

Over 240 million acres of land have been set aside by the Federal Government to protect some part of nature for generations to come. These lands represent and protect the best of the Nation's natural heritage and have become a source of national pride. Chapter 5 of volume 2 focuses on National Parks, Wilderness Areas, and National Wildlife Refuges, which comprise the bulk of the Federal lands held primarily for nature conservation.

Because a variety of human activities has altered or degraded the habitat for many species, federally protected natural areas have become repositories for the Nation's rarest species and sites for conserving biological diversity (181, 185). Protected natural areas are also subject to increased stress from activities that occur both within and outside their boundaries. Natural areas are being effectively dissected into smaller and smaller parts in some places-especially in the East-leaving them more vulnerable to other stresses that could degrade habitat quality and ecosystem health (103).

Under climate change, the climate "map" that has helped to shape natural areas will shift while the boundaries that define the management and degree of protection for natural areas will remain fixed (see fig. 1-6). As a result, the biological makeup of the protected natural areas will change. Some may become incapable of providing the benefits or serving the functions for which they were originally established, such as maintainingg their unique or distinctive character, providing protection for rare species and other biological resources, and maintaining the quality or availability of other services, such as nature study or certain kinds of recreation (see vol. 2, box 5-B).

Figure 1-6-Preserves and Climate Change



NOTE: As climate changes, the preferred range of many species may shift, leaving preserves dramatically changed.

SOURCE: Office of Technology Assessment, 1993.

Certain general characteristics of protected natural areas may make them more vulnerable to climate change, such as being small, isolated, fragmented, or already under considerable stress, and containing sensitive species or ecosystems, such as coastal, alpine, or Arctic ecosystems or midcontinent wetlands (67, 133, 188). If climate change leads to accelerated habitat loss or proceeds so quickly that some species cannot adapt quickly enough, species loss may accelerate, and overall biodiversity will decline (29, 196).

Even if species can move fast enough, adaptation by migration may be difficult because in many places, the landscape has been sectioned off into small pieces. Some natural areas are islands in the middle of extensively developed areas. Geographic fragmentation may limit the ability of

Box I-G-Climate Change in Alaska: A Special Case

Nowhere in the United States does there remain such a vast expanse of land so undisturbed by human activity as in Alaska. Because of its distinctive character, pristine conditions, and abundant natural resources, Alaska has become a national treasure. Nearly 66 percent of Alaska's land base is protected in wilderness areas, National Wildlife Refuges, National Forests, or public lands administered by the Bureau of Land Management (BLM). Alaska contains some 170 million acres (69 million hectares)[1] of wetlands (over 60 percent of the Nation's total) and 330 million acres of boreal forest. Alaskan plants and animals withstand some of the harshest environmental conditions in the world and many are unique to polar climates. Although human activities are to some extent adversely affecting this remote environment, it remains the most wild place in the United States and is rightly referred teas our "last frontier."

The unique characteristics of Alaska-the natural resources, the wildlife, and the pristine, harsh environment-affect nearly every aspect of life, including the culture and industry of those who live here. For example, traditions of the indigenous communities are deeply rooted In the distinctive wildlife and vegetation of Alaska. Many indigenous communities, such as the Inupiat Eskimos of Alaska's North Slope, still rely on wildlife and natural vegetation for subsistence. The bowhead whale is central to their culture. The whales are a major food source and the hunts are a community tradition. Caribou and fish are other staples for Inupiats. Athapaskan Indians, who reside mostly in the boreal forest of interior Alaska, rely heavily on the plant life there for food, housing materials, and heating fuels (120). Fish such as salmon and whitefish are primary elements of Athapaskan subsistence, and caribou and moose are important sources of food and clothing (120).

Alaska's economy is also deeply rooted in its abundant natural resources, with oil and gas, fishing, and tourism providing the base for the economy. Nearly 85 percent of the State's revenue comes from oil and gas exploration or development. Two of the largest oil fields in North America (Prudhoe Bay and Kuparuk fields) are located near Alaska's North Slope and provide the economic base for much of that region. Alaskan waters are also sites of sores of the world's most productive fisheries. The Bering Sea has the biggest fishery in the Untied States; it is among the biggest in the world. In 1990, Alaska's fish harvest(mostly salmon, king crab, halibut, shrimp, and scallops) surpassed any other State's, with more than 5.4 billion pounds (2.4 billion kilograms)[2] of seafood harvested-half of all seafood harvested in the Nation. The seafood industry is also Alaska's largest private-sector employer, employing 23 percent of the State's work force. In addition, Alaska's vast expanse of rugged land and abundant wildlife have made tourism a growing and important industry there. Visitors to Alaska spent almost $1 billion in 1989, the third largest source of income in the State. With 13,500 workers in tourist-related industries, tourism is second only to fisheries as a source of employment

Because climate changes resulting from rising atmospheric carbon dioxide ($C0_2$) are expected to be especially pronounced in Alaska and other high-latitude regions, Alaska may provide an "early warning" of initial climate effects. In very general terms, Alaska can expect to see increased average temperatures, increased precipitation, and melting of sea ice. The rate and ultimate severity of the climate changes is at present unknown (67). In addition, little is known about the sensitivities of wiidlife, vegetation, ecosystems, indigenous cultures,or the economy to any potential climate changes.

Warmer temperatures in polar regions are expected to lead to some melting of sea ice. A recent study of climate change effects on the Canadian Beaufort Sea determined that, based on a doubling of atmospheric CO_2, the open-water season could increase from an average of 2 months to 5 months, the extent of open water could increase from about 100 miles (160 kilometers)[4] to 300-500 miles, and maximum ice thickness could decrease

1 To convert acres to hectares, multiply by 0.405.

2 To convert pounds to kilograms, multiply by 0.454.

3 P. Carison, Alaska Division of Tourism, personal communication, September 1993.

4 To convert miles to kilometers, multiply by 1.609.

by 50-75 percent (102). Shoreline erosion could increase significantly with a longer open-water season. Overall biological productivity is also expected to increase in parts of the Bering Sea with an increase in temperature and change in ice cover. Because of the drying effects of warmer temperatures, there could be an increase in the frequency and extent of fires. Over the past three decades, fires in Alaska have increased due to warmer and drier conditions. More fires under climate change could expand the extent of early successional vegetation favored by moose, beavers, Arctic hares, sharptailed grouse, and other wildlife species. However, fire may adversely affect the lichen supply in spruce forests-an important food for caribou in winter.

The most profound consequence of warming in Alaska and other polar regions maybe the exacerbation **of** global climate change through the release of carbon from the permafrost of the Alaskan tundra and boreal forests. Worldwide, tundra and boreal forests contain nearly a third of the world's soil carbon. Thawing of the permafrost and the resulting decomposition of organic material, could release huge quantities of methane (CH_4) and CO_2 into the atmosphere and contribute to accelerated warming (67).[5] Climate warming may also be exacerbated by melting of the vast expanse of ice and snow that now reflects away considerable incoming heat Little can be done to stem the thaw and resulting secondary climate impacts, except to slow warming by reducing human-made greenhouse gas emissions.

Potential Losers

Indigenous cultures-Alaska's indigenous, subsistence communities could be at risk under climate change. Thawing of the permafrost is likely to affect supported structures such as pipelines and bridges, and roads may be threatened if thawing weakens the soil. Many indigenous peoples use the permafrost for food-storage cellars, so warming may threaten their ability to preserve food during summer months. Hunting the bowhead whale, an ancient and sacred tradition for many indigenous communities on the North Slope, is linked to the extent of sea ice. Melting of the sea ice will likely change the whale's migration and affect access to the whales by **indigenous** hunters.

Plants and animals--Nearly half of the world's peatlands (tundra) are in North America, with nearly a third of these in Alaska. Even a 2°F (1 °C) warming could lead to forests replacing alpine tundra on many mountains and islands (122). Some tundra species unable to adapt to climate change might decline. Caribou populations depend on lichens for food. The distribution of lichens is sensitive to the amount and extent of snow cover, which will change under a warming climate. Furthermore, because caribou calving is linked to vegetation produced during early snow melt, changes in the timing of the melt could disrupt calving.

Some 25 species of marine mammals regularly use Alaskan waters. The marine mammals most likely to be adversely affected by climate change are pinnipeds (seals and walruses) that winter primarily in the Bering Sea, have regular contact with ice, and are closely associated with the continental shelf or shelf edge. These include spotted and ribbon seals, which may suffer from increased competition with other species and reduced habitat, and Pacific walruses and bearded seals, which are ice-associated bottom feeders and are therefore tied to the seasonally ice-covered continental shelves. Both the beluga and bowhead whales are associated with sea ice, but they may not be significantly affected by melting because they do not depend on ice cover to protect and nurture their newborn.

Perhaps the biggest unknown impact of climate change is how it will affect fish populations and the fishing industry. Variations in stock size and species abundance appear to be correlated with periodic variability of ocean temperature, but are not completely understood. For example, huge fluctuations in groundfish stocks occur now.[6] Many scientists believe that overfishing will remain the primary concern for Alaskan fisheries (122). However,

5 Recent measurements indicate that the tundra of the North Slope of Alaska has in fact changed from a '(sink" to a "source" of CO_2 with the warming trend seen In Alaska over the past few decades (125).

6 V. Alexander, Dean, School of Fisheries and Ocean Science, University of Alaska at Fairbanks, personal communication, May 27, 1993.

(Continued on next page)

Box 1-G--Climate Change in Alaska: A Special Case--(Continued)

considering the importance of fishing to the Alaskan economy, the potential for loss under climate change is Significant

Potential Winners

Oil and gas industry-Reduction of the sea ice could allow the use of less expensive offshore structures and would reduce the costs of marine transportation. Some speculate that the opening up of the Northwest Passage would offer a shortcut for shipping from Europe to the Pacific Rim but Alaskan ports probably would not participate significantly in this traffic.

Plants and animals--In general, plant life is likely to benefit from an increase in temperature, though the composition of forests and other vegetated areas will likely change. Some boreal forest species, such as white spruce and birch, are likely to expand northward. Others, such as red and yellow cedar, may be less able to migrate because of the rugged terrain, low genetic variability, and slow dispersing ability. Some migration is already happening-white spruce ranges have been expanding over the past 40 years. Expansion of white spruce into boreal forests may eventually be important for timber harvests.

Most wildlife species, including polar bears, moose, musk-oxen, mountain sheep, most marine mammals, and many birds (e.g., grouse, raptors, owls, and migratory birds), will likely benefit from increased temperatures and increased productivity in vegetation. These benefits might be stemmed by losses of tundra wetlands, increases in disease spread, or changes in species assemblages that would result in changed predation patterns. Most birds will likely benefit from having more forage, more insects, and a longer season during which to rear their young. Omnivores such as bears should respond favorable to a changing climate because of the longer availability of green vegetation in the spring. Other forbearers and carnivores should increase in response to larger prey populations unless they are controlled by hunting, trapping, or other human activities.

Tourism--Higher temperatures are likely to benefit the tourism industry, although vigorous advertising by the State has almost certainly had more impact on the industry in recent years than has its climate. increased wildlife populations will probably attract more hunters, hikers, and campers. However, increased tourism could also mean more impacts on the environment that is so important to indigenous, subsistence communities.

species to find new habitat-they may have no place to go (34).

Natural areas in the West are currently much larger and much less fragmented than they are in the East. However, the institutions that manage these lands are designed to manage only their own parcels-in isolation-and are not encouraged to consider the often more extensive natural ecological system. This compartmental approach to management, or *institutional fragmentation,* may prevent effective solutions to problems that transcend individual management parcels, such as those posed by climate change (64, 92).

The main challenge for policy is to maintain the high value of the system of natural areas while realizing that climate change may affect the very factors that make natural areas valuable: character, species protection, and environmental services. The ideal response to this challenge might be some combination of three general management approaches: 1) maintain species where they are today, 2) help species migrate through more intensive management, and 3) acquire lands that will be valuable under a changed climate. However, the lack of adequate knowledge and information precludes the full implementation of either approach now.

It is difficult to predict how climate change will affect natural areas and how they will respond. his lack of knowledge limits the ability to help natural areas adapt. We do not know which species are most sensitive to climate change, which could be saved, or how to recreate habitats or entire ecosystems elsewhere. The limited success with restoring populations of endangered species illustrates how little is known about restoring species and their natural habitat. In addition, we do not know what lands will be most valuable as preserves under climate change. We do not even know all of the species and kinds of ecosystems currently under formal protection in preserves today.

The most useful approaches that the Federal Government could take to facilitate adaptations to climate change in natural areas fall into two categories: information gathering (including research, inventory, and monitoring options) (115, 171), and managing natural areas now to minimize the impediments to adaptation and to increase their resiliency. The second category includes taking direct Federal action to influence the management of natural areas, establishing incentives to private landowners to encourage conservation under uncertainty, and promoting larger-scale management through more partnerships among agencies, communities, and governments. A variety of options that address these needs are assessed in volume 2, chapter 5.

Because money to implement every policy option and the scientific understanding of how climate change will affect natural areas are limited, we have identified some strategies that represent inexpensive or useful frost steps for facilitating adaptation to climate change in natural areas. These options meet at least one of several criteria: they will take a long time to complete; they address "front-line," or urgent, issues that need attention before informed policy decisions can be made; they can be approached through mechanisms that are already in place or through efforts already under way; and/or they have benefits in addition to those that help prepare for climate change. In some cases, a near-term legislative action will provide a target of opportunity to pursue these options.

- Use the National Biological Survey (NBS) to assess ecological inventory and monitoring needs. Future strategies to protect natural areas and their resources will require a national picture of current biological resources and the extent of the protection of--or the threat to-these resources. A national inventory and monitoring program would be particularly beneficial in supporting efforts to protect endangered species and biodiversity. DOI's proposed new National Biological Survey presents an opportunity to implement some of these activities (131, 132, 188). Congress could ask NBS to initiate a nationwide inventory and monitoring program, synthesize ecological and biological information for managers and planners, establish a mechanism for facilitating regional-level research and management, and develop a priority plan for expanding protection of natural areas.
- Support basic research on key gaps in our understanding of ecosystems. This research would include work on species sensitivity to climate change, restoration and translocation ecology, the design and effectiveness of migratory corridors or protective buffer zones, the development of ecological models, and the effect of elevated CO_2 concentrations on plants and animals. Basic research in these areas is needed now to determine how species might respond to climate change and how best to provide for their protection in the future.
- Conduct a review of ecological research within USGCRP and across Federal agencies. Such a review would evaluate how much ecosystem research relevant to climate change and other long-term ecological problems (e.g., loss of biodiversity) is being done, and would identify important gaps. A review of all research on 'natural resources' has not yet been conducted across the Federal agencies. Existing analyses suggest that a great deal of money is spent on

research relevant to the environment, but how much is useful to understanding long-term ecological problems is not known. Further, there is currently no mechanism for consolidating results from disparate research efforts into ‘‘general patterns and principles that advance the science and are useful for environmental decisionmaking. Without such synthesis studies, it will be impossible for ecology to become the predictive science required by current and future environmental problems’ (97). An effort to characterize and synthesize ongoing research could help bridge the gap between basic research and natural resource planning. Such a review could be conducted by the Office of Science and Technology Policy, the National Academy of Sciences, or an independent commission.

- Provide funding for the Fish and Wildlife Conservation Act of 1980 (P.L. 96-366). This law establishes a Federal cost-share program for “nongame” species conservation. It has already been enacted, but has never been funded. Many States have prepared initial plans that could qualify for Federal matching funds, making it a target of opportunity to promote natural area conservation at the State level. With some amendments to promote multispecies, or ‘‘ecosystem, protection at the State level and adequate funding, the Fish and Wildlife Conservation Act could be used to encourage natural area protection and conservation on State and private lands.
- Use acquisition strategies to enhance protection. Federal land-management agencies should be directed to consider whether all future land acquisitions and exchanges: 1) augment underrepresented ecosystems in the Federal natural area holdings, 2) buffer or connect other preserved land parcels, and 3) provide habitat or services likely to persist over the long term despite anticipated stresses. Setting aside a given amount of land within the modem fragmented landscape does not alone ensure that the ecological features for which it is valued will be preserved. To best conserve species, natural areas should include an array of ecosystems and transition zones between them to allow for the many complex interactions that rely on links between different parts of the landscape. By asking agencies to incorporate such concerns into future acquisitions, Congress could minimize future geographic fragmentation and use limited monies to maximize the range of protected ecosystems.

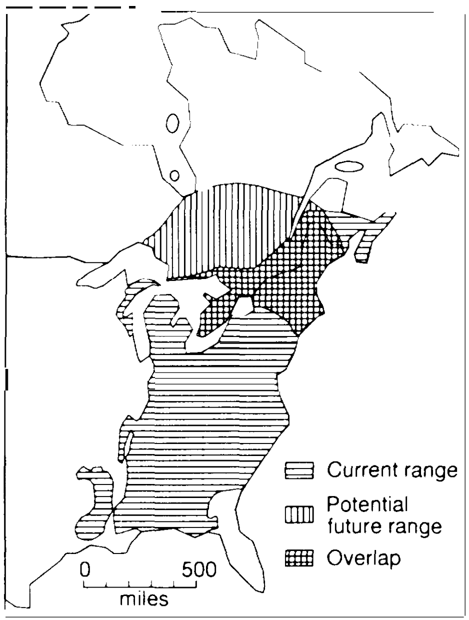
Forests

Forests cover roughly one-third of the U.S. land area, shaping much of the natural environment and providing the basis for a substantial forest-products industry. These forests are enormously variable, ranging from the sparse scrub of the arid interior West to the lush forests of the coastal Pacific Northwest and the South. The Nation’s forests provide essential fish and wildlife habitat, livestock forage, watershed protection, attractive vistas, and an array of recreational opportunities. Timber is one of the Nation’s most important agricultural crops.

Climate change may pose a significant threat to forests, particularly forests that are not actively managed for timber production. Within a century, climate change might shift the ideal range for some North American forest species more than 300 miles to the north (see fig. 1-7). Such a shift would almost certainly exceed the ability of natural forests to migrate (35, 36, 146). Forests stranded outside their ideal climatic range could suffer from declining growth and increased mortality from climate-related stresses such as insects, disease, and fires (2, 58, 100, 157). Some forests may collapse, and species and unique populations may be lost from isolated ranges if climate change is too rapid.

The most vulnerable forest resources are those in regions subject to increased moisture stress, as

Figure 1-7-Current and Projected Range of Beech Under Climate Change



NOTE: Based on climate projections from the Goddard Institute for Space Studies GCM under the assumption of a doubling of atmospheric CO_2. To convert miles to kilometers, multiply by 1.609.

SOURCE: Office of Technology Assessment, 1993, adapted from M.B. Davis and C. Zabinski, "Changes in Geographical Range Resulting from Greenhouse Warming: Effects on Biodiversity in Forests," in: Global *Warming and Biological Diversity,* R.L. Peters and T.E. Lovejoy (eds.) (New Haven, CT: Yale University Press, 1992).

in the dry continental interiors (14, 15, 159, 191). Forests in coastal regions may be at risk from rising sea levels, with the threat of flooding and saltwater intrusion, or from increases in damaging wind storms (61, 106). Forests with small or highly fragmented ranges may be lost, such as those at the upper elevations of mountains with nowhere to migrate (89). Forests in locations already subject to droughts, free, and wind damage will be at high risk if the frequency or intensity of these stressors is increased (157).

The extent to which intervention to facilitate adaptation may be practical or desirable is limited. Even timber-industry forests are not intensively managed by the standards of annual agricultural crops. On large areas of public forest lands, even a minimal management response might be viewed as incompatible with the goals for which the forest is held. The challenge is to find unobtrusive and cost-effective means to help ensure that the health and primary services of the Nation's forest resource will not be lost if climate change proves to be as serious a threat to forests as some believe it will be.

The Federal Government can prepare itself to respond to the threats that climate change poses to forests in several ways: 1) by better understanding which forests are at risk (e.g., by supporting research on species sensitivity to climate and monitoring changes in forests); 2) by acting to avoid the potential loss of forest species (e.g., by promoting and improving forest seed banks, mass propagation techniques, and forest-restoration techniques); 3) by being ready to react promptly to the threat of large-scale forest mortality (e.g., by preventing fires, managing pests, or thinning to promote drought tolerance—in forests where such activities are determined to be appropriate); 4) by redirecting incentive programs to encourage improvement in the health of private forests; and 5) by increasing the adaptability of the forest industry and forest-dependent communities to climate change through forest-product research and incentives for diversification.

Given the existing policy levers, the limited money to fund programs, and the poor level of scientific understanding of impacts of climate change on forests, the following subset of policies, discussed in volume 1, chapter 6, are frost steps that Congress could take. Each would help the Nation begin to position itself to respond to the effects of climate change on both timber and nontimber forests. These options are justified now either because of existing problems (such as free, pests, and drought) that will be exacerbated by climate change, or because of the time required to complete the process.

- Establish an expanded forest seed-bank program. A rapid climate change could threaten the genetic diversity of U.S. forests. A national effort in the conservation of forest seeds would provide an opportunity to respond to the potential for loss of genetic diversity in the forest resource under climate change. An appropriate goal for such a program would be to maintain sufficient seed variety, or other genetic material, so that much of the original diversity of the Nation's forests could eventually be restored (86, 87). (Current forest seed-collection activities are uncoordinated and focused on only a small number of species (113).) To accomplish this goal, Congress could authorize and fired a National Forest Genetic Resources Program within the Forest Service, providing funds for the construction and operation of seed-storage facilities, for the establishment of associated plantations to be used for continuing, seed production, and for a forest genetics research program that would address climate tolerance of trees and means for large-scale propagation. Such a program could be partially supported through fees for private access to the seed collection.

- Develop strategic plans for responding to major forest declines. Increased risk of fries and insect damage may result under a warmer climate. The relative value of prevention activities to reduce risk is likely to be increased. The need for aggressive intervention to protect forest resources may also be increased. Because of the need for prompt action and because of the contentiousness that often accompanies forest management, policy rules for pest-control activities and silvicultural management to reduce forest health risks are best established before they are needed. Congress could enact a forest-health bill that would establish criteria that would allow prompt action to protect against threats of catastrophic mortality or restore forests after large-scale mortality and decline. Such a bill might allow for the declaration of temporary forest-health emergencies, under which accelerated actions to protect or restore forest health would be authorized-as long as these actions were consistent with established standards for protection of all forest values. A policy-review group made up of academics, representatives of interest groups, and Federal forestry personnel could develop criteria for undertaking actions to stem forest decline.
- Prepare for a forest-management response to climate change. A changing climate may eventually require innovations in forest-management and planting practices. Experimental efforts will be important in establishing a scientific basis for any necessary changes to future management practices that might later be applied to public multiple-use forests. Congress could support a program of research on the Forest Service's Experimental Forests, or other research facilities, to address adaptation to climate change. The Experimental Forests are already designated as outdoor laboratories for evaluating forestry practices. The research could be directed toward finding practical and environmentally appropriate techniques for managing the public forests that will help buffer them or help them adapt to a changing climate.
- Improve incentives for private management of forest lands. The Federal Government controls only about one-quarter of the Nation's forestland. In the East especially, where Federal holdings are limited, efforts to support the protection of private forestland may take on increased importance. The Federal Government may use incentives, disincentives, and cooperative approaches to promote the health and productivity of this forestland. Existing subsidy programs under the Cooperative Forestry Assistance Act of 1978 (P.L. 95-313), as amended by the 1990 Farm Bill, provide cost-sharing assistance to owners of small, private forests. Traditional

forest-support programs (e.g., the Forestry Incentives Program) target funds on the basis of potential gains in timber supply. These programs could be modified so that funds could be targeted to areas at high risk of insect and fire damage and to ecologically valuable forestland, which would encourage activities that maintain the health of the private forestland and discourage the further fragmentation of forestland. Expanding the role of the Forest Stewardship and Forest Legacy Programs might help to accomplish these goals. The funding priorities of the Forest Stewardship Program could be clarified, thus ensuring that most funds are targeted to the areas identified above.

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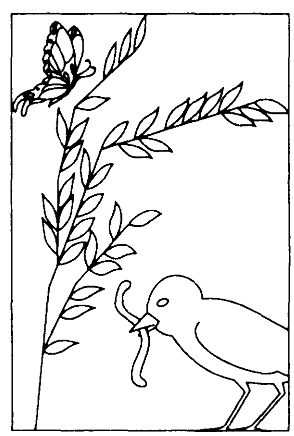
A Primer on Climate Change and Natural Resources 2

This chapter summarizes the current state of knowledge about climate change and describes the interaction of climate variables with natural systems. Background information key to understanding the impacts described in each of the resource chapters (coasts, water, agriculture, wetlands, preserves, and forests) is included here. This chapter illustrates the range of effects climate change could cause across systems and at different spatial and temporal scales.

Human activities have increased the rate at which greenhouse gases-carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs)-are building up in the atmosphere. This increase is likely to lead to changes in climate that could have significant effects on natural systems. The first-order effects of a buildup of greenhouse gases-increasing average temperature, rising sea level, and changes in precipitation and evapotranspiration--can be estimated with some confidence at the global scale. Global average temperature may increase about 2 OF (1 ‘C) by 2030 and sea level is predicted to rise by about 8 inches (20 centimeters)[1] in the same period; precipitation and evapotranspiration globally will also increase.

As scientists consider smaller spatial scales, their certainty about these effects decreases. Some midcontinent regions are likely to become warmer and drier rather than warmer and wetter, for example, but not enough is known yet about climate change on a regional scale to be confident about the direction and magnitude of changes. A decade or more of research will be needed before such precision is available. Second- and third-order effects, such as changes in individual plants and animals or whole ecosystems, are ultimately the impacts that humans care



[1] To convert inches to centimeters (cm), multiply by 2.540.

about. These changes in the natural and managed systems that societies depend on have socioeconomic consequences and result in costs or benefits.

Plants and animals are more immediately affected by extreme events, such as droughts, floods, or storms, than they are by changes in the long-term averages of climate variables. However, individuals may not be able to tolerate sustained changes in average temperature and precipitation. Such conditions might, for example, lead to increased vulnerability to pests, disease, and fires. Repeated stress will adversely affect not only individuals but also populations and species, potentially resulting in altered ecosystem ranges and composition.

As the climate changes and average temperature increases, the extremes experienced by ecosystems will change as well. The hottest temperatures may be hotter than previously experienced; the coldest temperatures may not be as cold as they are now. Ultimately, temperature shifts may alter the geographic range of species and ecosystems. Climate change may also benefit some plants and animals. Certain plants, for example, may derive benefits from the rising concentration of CO_2 in the atmosphere, which can act like a fertilizer. Higher temperatures could enable some plants and animals to increase their geographic ranges.

Ecosystems are always changing and would continue to do so without climate change. However, projected rates of change in temperature exceed the estimated rates for the past 15,000 years, which averaged about 2OF(1‘C) per 1,000 years; under a changing climate, temperatures could rise 3 to 8 OF (1.5 to 4.5 ‘C) over the next century. These changes may be too rapid to allow forest ecosystems to migrate with the changing climate. Atmospheric concentrations of $C0_2$ are changing 30 to 100 times faster than shown in ice-core records, which go back millennia. Natural ecosystems are more vulnerable to climate change than are managed ones, such as fares and plantation forests, because active measures-irrigation, replanting, and fertilizing, for example--are much more difficult to undertake in natural areas.

U.S. FISH AND WILDLIFE SERVICE

Many animals, such as this Roe@ Mountain coyote, require large expanses of remote and undisturbed habitat to sustain populations. Human disturbance or fragmentation of habitat leads to declines in prey populations and vegetation cover. Affected species can migrate, decline, or alter their food sources.

Many natural systems are already degraded by pollution and geographic fragmentation. Additional human-caused stress may lead to undesirable changes in the values and functions of natural systems from which humans now benefit. ‘Under stress, natural systems of plants and animals tend to breakup and reformulate in new systems with different species or mixes of species” (21). The total change in an ecosystem depends not only on its sensitivity to climate change, but also on the system’s absolute sensitivity to a variety of other changes that influence soil and water chemistry or habitat fragmentation (21).

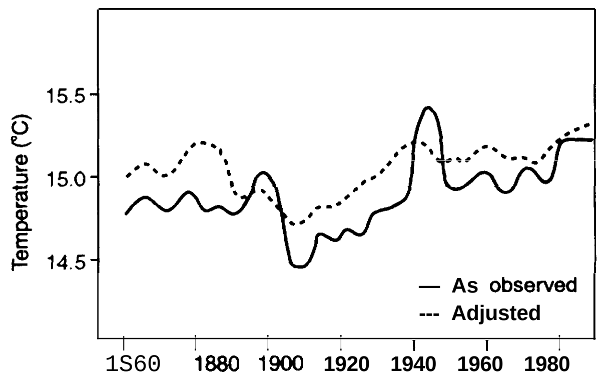
HOW DO WE KNOW CLIMATE IS CHANGING?

The Earth’s average temperature has increased 0.8 OF (0.45 ‘C) over the past 100 years, with an uncertainty range of +/-0.27 OF (+/-0.15 °C). The broad range reflects many inaccuracies introduced in the 100-year land-based temperature record by recording temperatures in cities (which tend to be warmer than rural areas),[2] using different instruments over time, and inadequate and changing spatial coverage.

Because the climate system is so inherently variable, it takes a long time to detect trends. Besides greenhouse gases, urban ozone, decreases in stratospheric ozone, increases in acidic air pollution, volcanic aerosols, and the solar cycle are all likely to have influenced the observed global temperature record. For example, the sum of all known greenhouse gases emitted to the atmosphere to date should have increased the heat-trapping capacity of the atmosphere by 2.1 watts per square meter (W/m^2). However, over the past few decades, other forces could have counteracted as much as 50 percent of the effect by cooling the earth. Urban air pollution (e.g., soot and acid aerosols) could have offset the warming by up to 24 percent, ozone depletion by CFCS, 10 percent, and increased cloudiness by 20 percent. Although these cooling effects temporarily mute the greenhouse effect, they do not negate it, so net warming is expected. Simultaneously, solar irradiance (the output of the sun) may have enhanced the greenhouse effect by 14 percent.

Other naturally occurring events can confound the temperature record, too, such as the 3- to 7-year occurrences of El Niño. Volcanic eruptions (such as El Chichon in 1982 and Mount Pinatubo in 1991) can more than offset the entire greenhouse effect temporarily (for 2 to 4 years).[3] Recent satellite temperature measurements taken over a 12-year period show no warming trend (84). This satellite record cannot be used to refute global warming for three reasons: 1) the record of measurements is over too short a period; 2) two major volcanic eruptions occurred during that period (Chichon and Pinatubo), followed by a several-year cooling due to the particles they injected into the atmosphere; and 3) the satellite does not measure the near-surface temperature of the earth; rather, it integrates a 6,500-yard (6,000-meter) swath of the atmosphere (48).

Figure 2-l—Long-Term Global Temperature Record



NOTE: Global average temperature from raw observations (solid line) vs. data adjusted for known biases (dashed line). Lack of data quality and continuity has led to an undesirable level of uncertainty about these records. To convert °C to °F, multiply by 1.8 and add 32,

SOURCE: T.R. Karl, "Missing Pieces of the Puzzle," in: Research and *Exploration,* Spring 1993, pp. 235-49.

Despite all the confounding factors, the long-term temperature record shows warming that is consistent with that calculated by the general circulation models (GCMS) (44) (see fig. 2-1 and box 2-A). The observed 0.8 OF rise is within—but at the low range of—the 0.7 to 2.0 OF (0.4 to 1.1 °C) that models predict. The warming is not "statistically significant''--that is, it is not outside the range of normal variability. The unequivocal detection of a climate change signal from such complicated records requires at least another decade of measurements (44). The nine warmest years since 1891 were all in the 1980s and early 1990s (6). Several ancillary pieces of evidence consistent with warming, such as a decrease in Northern Hemisphere snow cover, a simultaneous

[2] Bias due to 'the heat island effect' is likely to be less than 0,1 °F (0.05 'C), or less than 10 percent of the observed temperature increase (43).

[3] For example, Pinatubo injected 25 million tons (23 billion kg) of sulfur dioxide 15 miles (25 km) into the stratosphere; the cooling caused by reflectivity of those particles should offset the warming from greenhouse gases for 2 years until the particles settle out of the atmosphere.

Box 2-A–What the Models Tell Us: GCMs and Others

To describe how the climate system operates and to predict how changes in the composition of the atmosphere will affect climate, scientists have developed models known as *general circulation models (GCMs). GCMs* are composed of mathematical equations that describe the physical climate processes and interrelationships, including seasonal changes in sunlight, global air currents, evaporation and condensation of water vapor, and absorption of heat by the oceans. The models incorporate basic physical principles (such as the conservation of energy and mass) and empirical evidence from observations of how the climate system seems to operate (such as statistical equations describing the humidity and temperature at which clouds generally form). The four major GCMs have generated somewhat different predictions about how climate might change largely because they use different empirical evidence and starting assumptions and incorporate different sets of climate variables. Even models that agree on global averages may predict different regional distributions because they have different ways of accounting for small-scale climate processes.

The differences in climate change predictions from the various major climate models have drawn considerable attention. So, too, has the fact that observed changes in global average temperature have been lower than initial estimates. Many models have predicted that based on the increases of human-generated greenhouse gas emissions (particularly carbon dioxide (CO_2) emitted during fossil fuel combustion) over the past century, global temperatures should already have increased by 0.5 to 2.0°F (0.3 to 1.0°C). Measurements of warming to date suggest that global average surface-air temperatures have increased approximately 0.5 to 1.0 °F (0.3 to 0.6 °C)-on the low end of the predicted range (45).[1]

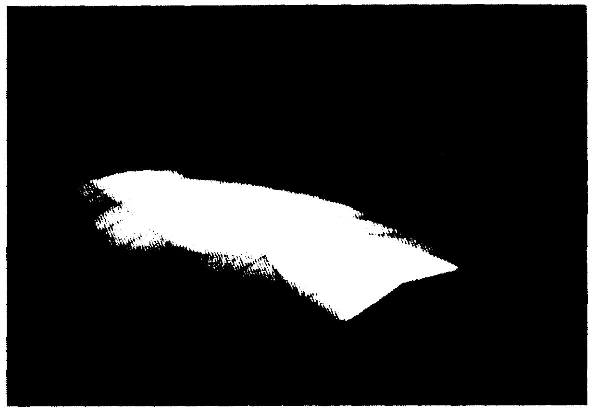
That global warming appears to be proceeding more slowly than predicted maybe due to difficulties in distinguishing short-term climate patterns from long-term trends, as well as to the complex and incompletely characterized interactions of oceans, clouds, and air pollution with weather and climate (44,92). Natural variations in weather(e.g.,rainfall and temperature) occur over years or decades, which may mask longer-term (century and millennium) climate patterns for many years (83). in addition, oceans have an enormous capacity to absorb heat, which may delay atmospheric warming for some time (81, 88). Clouds also play an important but uncertain role in moderating planetary climate. Depending on their composition and location, clouds may either cool the planet by reflecting incoming solar radiation or warm it by contributing to the greenhouse effect,so it is not clear whether, in the aggregate, they contribute to or somewhat offset global warming (1,88). Finally, global warming maybe offset somewhat in the Northern Hemisphere because sores human-generated pollution (particularly sulfur aerosols) may actually exert a cooling effect: when converted to sulfate particles in the atmosphere, they reflect incoming solar radiation (44, 88).

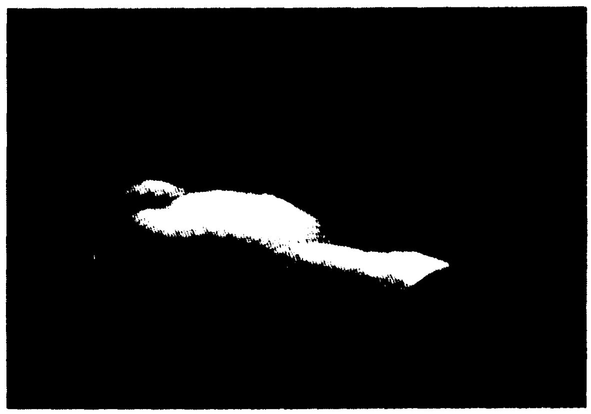
Generalities and uncertainties

GCMs paint the following general picture of global climate change. Average global air temperatures will increase. With increased temperatures will come an increase in average global precipitation because warmer air causes faster evaporation, speeding up the rate at which water vapor becomes available for cloud formation and precipitation. Increased temperatures will cause the water in oceans to expand (water expands as it warms above 39 °F (4 °C)), and as ocean volume increases, sea levels will rise. Sea level rise may be moderated if increased

1 Global-average temperature statistics are compiled from historical temperature measurements from weather stations around the world. Accurate Interpretation of historical temperature data is complicated and controversial because changes In measurement techniques and locations over the past century make the data difficult to compare. Data analysis is further complicated by the urban "heat Island effect"--local warming In areas with many buildlngs and paved surfaces that tend trap heat-which has raised temperatures at some monitoring stations, reflecting changes In local climate apart from any potential global changes. The estimated temperature change reported here was a consensus figure developed by the Intergovernmental Panel on ClimateChange (IPCC) that attempts to account for both the changes in measurement and the confounding effects of data from urban areas.

temperature and water-holding capacity of the air lead to more snow at the poles, which may cause arctic ice sheets to grow thicker in the near future; on the other hand, warmer temperatures could cause parts of the Greenland and Antarctic ice sheets to melt, causing even more sea level rise. Beyond these generalities, significant uncertainties remain about regional impacts, *rates of change,* and *feedback* Regional predictions are quite murky, and they are the ones that are most important to individual resources and human societies. A variety of factors, including local or mesoscale effects of hills, and vegetation boundaries, are Important in determining regional climate. GCMs cannot at present incorporate features this small (see the figure in this box) because spacing between grid points is between 150 and 800 miles (250 and 1,000 kilometers)[2] (94). Because models differ in how they treat these physical features and because the current generation of models is only beginning to incorporate the modeling of ocean currents and cloud cover, it is not surprising that the major GCMs differ markedly in predicting regional changes in precipitation, soil moisture, and other hydrologic variables. For example, certain models predict that precipitation will increase in some regions while others suggest that it will decrease (83). The range (and therefore uncertainty) in model output for soil moisture and runoff is even greater than it is for precipitation (49).





NOTE: Models cannot yet incorporate regional features adequately because grid sizes are too large. The smaller the grid size, the more complex and time-consuming each model run becomes. The top figure shows how a 460-km grid can obscure important geologic features. The bottom figure shows what the topography of the United States looks like with a 120-km model grid. The degree of resolution In the bottom figure is typical of present global weather prediction models.

SOURCE: National Center for Atmospheric Research.

Most climate modelers agree that precipitation is most likely to increase at high latitudes and that the water-holding capacity of the atmosphere (cloudiness) will be largest in low to mid latitudes (30). In the midcontinent areas, especially in summer, evapotranspiration may outstrip precipitation, and thus soil moisture and runoff would decrease. The potential for more-intense or longer-lasting droughts would therefore increase. Some scientists (78) suggest that GCMs (because of their lack of realistic land-surface models) understate the potential for the intensification of summertime drought in low to midlatitudes. If current trends in greenhouse gas emissions continue, they predict, the frequency of severe drought in the United States would be expected to increase dramatically, with effects becoming apparent sometime on the 1990s (78).

A second likely regional consequence of global warming is that it will lead to changes in the type and timing of runoff. Snowmelt is an important source of runoff in most mountainous areas. Warmer temperatures in such

2 To convert miles to kilometers, multiply by 1.609.

(Continued on next page)

Box 2-A–What the Models Tell Us: GCMs and Others--(Continued)

areas would cause a larger proportion of winter precipitation that now fails as snow to fail as rain. Thus, the proportion of winter precipitation stored in mountain snowpack would decrease. Winter runoff would increase, and spring runoff would correspondingly decrease. During times when flooding could be a problem, seasonal changes of this sort could have a significant impact on water supplies because adequate room in reservoirs would have to be maintained (53), and thus some early runoff would probably have to be released.[3]

Uncertainty surrounds predictions of the rate at which climate change may proceed. Most assessments of climate change have assumed that it will proceed gradually and continuously until the climate reaches some new equilibrium (21). These assessments attempt to characterize what the climate might eventually be like when the equivalent of doubled $C0_2$ has been reached; relatively few studies have examined the intermediate,or transient, climate stages. However,a few suggest that the change may not be linear and gradual. For example,the capacity of the oceans to absorb heat may delay warming for some time, but there maybe some threshold after which ocean heat absorption slows and a relatively rapid warming of air temperatures follows (81)-or proceeds in steps in a series of punctuated equilibria (relatively rapid change for a short time followed by a period of relative stability), so transient climate stages might be important (15).

Uncertainties also arise from lack of knowledge about potential climate feedbacks--that is, processes that occur in response to global warming that either augment or diminish the effect in complex and interacting ways. For example, at warmer temperatures, the atmosphere can hold more water vapor, which is a powerful greenhouse gas, and this will magnify warming. On the other hand, some portion of the additional water vapor could form into clouds, which can, depending on their size, shape, and distance from the Earth's surface, reflect solar radiation and either amplify or offset some of the warming. The role of ice and snow in climate systems has not yet been quantified, and it is not dear whether it will prove to be an additional feedback. Warming in the polar regions will likely melt sores portion of the polar ice caps, reducing the extent of land and wean covered by them. Ice and snow are more reflective than either land or water; redwing the amount of ice and snow will allow both land and seato absorb more heat. In addition, sea ice tends to insulate the ocean; when the ice is not present, the ocean may release heat to the atmosphere more readily. Both processes could add to the warming cycle, so that as the atmosphere becomes warmer, it triggers various additional processes that will make it warmer still (88).

Other feedbacks may, however, counteract warming. For example, some scientists point out that vegetation may grow better in an atmosphere with higher concentrations of CO_2. Increased plant growth could allow plants to take up mom carbon from the atmosphere, potentially acting as a brake to greenhouse warming (61).

Despite the uncertainties attached to climate change predictions,there are many areas of agreement on the global, and even some regional, outlines of change. The effects on ecosystems and natural resources are more uncertain. Even if models could now generate accurate regional and local climate predictions, scientists do not yet have the theoretical knowledge to predict with confidence how ecosystems will react to the predicted climate changes--and how ecosystem response will translate into impacts on natural resources and on the people who depend on then And they are further still from being able to forecast how or whether systems could adapt.

3 The California Department of Water Resources has estimated, for example, that if average temperatures warm by5°F (3 °C), winter snowmelt runoff would increase, but the average April-July runoff would be reduced by about 30 percent (M. Roos, Chief Hydrologist, California Department of Water Resources, personal communication, 1992).

SOURCES: Intergovernmental Panel on Climate Change (IPCC), World Meteorological Organization, and United Nations Environment Program, *Climate Change: The IPPC Scientific Assessment*, report prepared for IPCC by Working Group I, J.T. ., [illegible] . Ephraums (eds.) (Cambridge, England: Cambridge University Press, 1990); Intergovernmental Panel on Climate Change, World Meteorological Organization, and United Nations Environment Program, *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*, report prepared for IPCC by Working Group i, J.T. Houghton, B.A. Callander, and S.K. Varney (eds.) (Cambridge, England: Cambridge University Press, 1902); U.S. Congress, Office of Technology Assessment (OTA), *Changing by Degrees: Steps to Reduce Greenhouse Gases*, OTA-O-42 (Washington, DC: U.S. Government Printing Office, February 19S1).

decrease in Arctic sea ice, continued melting of alpine glaciers, and a rise of sea level (48), have also been corroborated.

WHAT CAUSES CLIMATE CHANGE?[4]

The Earth's atmosphere is a natural greenhouse. Sunlight passes through the atmosphere and strikes the Earth, and as the planet warms and radiates heat, a large share of the heat is trapped by gases in the atmosphere, primarily Co_2 and water vapor. Although these gases make up only 0.25 percent of the atmosphere by volume, they are responsible for increasing the average temperature of the Earth from O OF (the temperature it would be without these natural greenhouse gases) to 59 oF. The evolution of such an atmosphere offered the appropriate conditions for the development of life on Earth. Humans have added more CO_2 and other greenhouse gases (CH_4, N_2O, and CFCS) to the atmosphere over the past 100 years. These gases effectively trap the heat that would normally be radiated from the earth into space. Instead, heat is reflected back to the Earth, and both the surface and the lower atmosphere get warmer-causing global warming. This greenhouse effect is illustrated in fig. 2-2.

An international panel of scientists was established in 1988 to assess potential climate change and its impacts. This Intergovernmental Panel on Climate Change (IPCC) includes more than 50 countries, and operates under the aegis of the World Meteorological Organization and the United Nations Environment Program. IPCC issued a report in 1990 and an update in 1992 (44, 45) that represent the best scientific assessment to date about climate change and its causes. IPCC scientists agree on the basic atmospheric mechanisms that make the planet a greenhouse. They also concur that human activities, such as burning fossil fuel, deforestation, and agriculture, have increased the rate at which greenhouse gases are emitted to the atmosphere, and that the concentrations of those gases in the atmosphere are increasing.

WHAT CHANGES IN CLIMATE ARE PREDICTED?[5]

Carbon Dioxide and Other Greenhouse Gases

In contrast to measurements of temperature and precipitation, which do not reveal clear trends, measurements of greenhouse gases show significant, steady increases over the past century.[6] For example, the concentration of atmospheric $C0_2$, the most important greenhouse gas (other than water vapor), has been systematically monitorted since 1958 at the Mauna Loa Observatory in Hawaii.[7] It has been increasing steadily for the past 35 years. Data from air bubbles in ice cores show that preindustrial atmospheric $C0_2$ concentrations were 280 parts per million (ppm); in 1990, the concentration had increased by more than 25 percent to an annual average of 353 ppm and is increasing at 0.5 percent per year (see fig. 2-3, lower data points). Seventy to 90 percent of the $C0_2$ added to the atmosphere today (about 8

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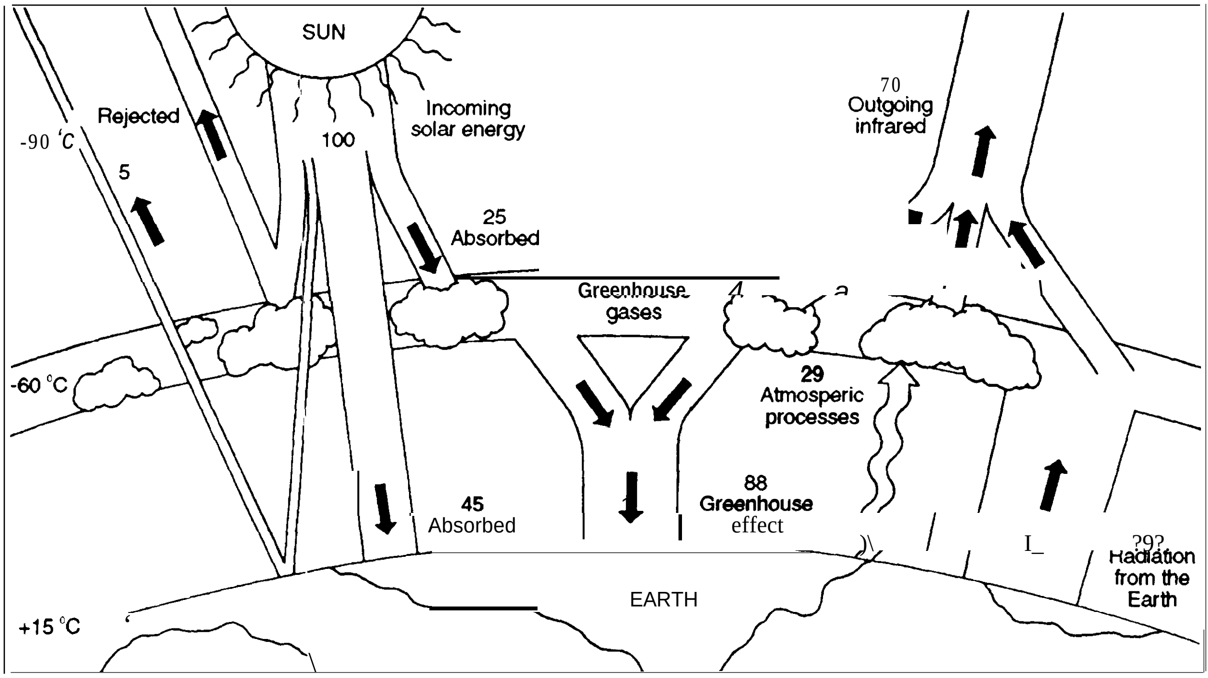
[4] This section briefly summarizes the mechanisms **and the greenhouse gases that** contribute to the greenhouse effect. For a more detailed treatment of climate change, see chapter 2 of OTA's previous report on **climate** change, Changing by Degrees (88). That report also examines how the United States and other countries could reduce emissions that contribute to climate change,

[5] **The** predictions given throughout this section are based on an equivalent doubling by 2025 to 2050 of greenhouse gas concentrations **from** preindustrial levels. In **addition,** the predictions refer to a future *equilibrium* ***climate—that*** *is, one in which the climate has* **finished changing** *and the* climate system has **arrived** at a new b**alance—rather** than the ***transient climate,*** or intermediate stage, that occurs as climate change is underway. Scientists debate whether the climate will reach a new equilibrium or **whether** we are instead entering an era of continuous change. Equilibrium may not be reached for centuries. (J. **Mahlman,** Director, Geophysical Fluid Dynamics Laboratory, Princeton University, July 28, 1993, at a briefing sponsored by the World Resources Institute and the National Oceanic and Atmospheric Administration.)

[6] For a **more detailed** discussion of the emissions and effects of **greenhouse gases, see reference 88.**

[7] $\mathbf{CO_2}$ is responsible for about 70 percent of the radiative forcing (heat trapping) caused by greenhouse gases in the 1980s.

Figure 2-2—The Greenhouse Effect



NOTE: Radiation flows are expressed here as a percent of total incoming or outgoing energy. Incoming solar radiation is partially reflected back into space (30 percent) and partially absorbed by the atmosphere, ice, oceans, land, and biomass of the Earth (70 percent). The Earth then emits radiant energy back into space. The "greenhouse effect" refers to the trapping of some of the radiant energy the Earth emits by atmospheric gases, both natural and anthropogenic. As a result of this effect, the Earth's surface and lower atmosphere warm.

SOURCE: U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps to Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: Government Printing Office, February 1991).

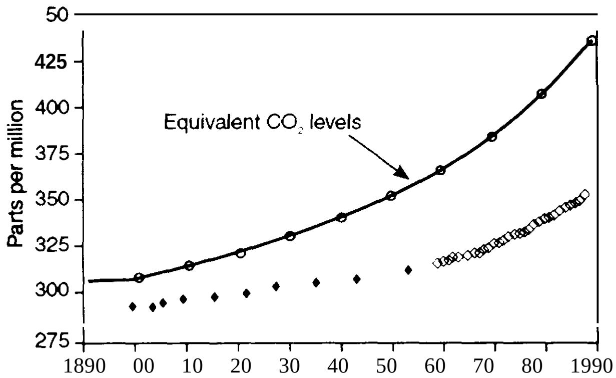
to 9 billion tons, or 7 or 8 trillion kilograms, of carbon each year) is due to the burning of fossil fuels--coal, oil, and natural gas; the remainder is attributed to deforestation. IPCC notes that under a "business-as-usual" scenario, the concentration of CO_2 could rise as high as 800 ppm—nearly triple the preindustrial level-by the end of the next century (44). If world emissions were frozen at 1990 levels, CO_2 concentrations would still rise to 400 ppm by about 2070 (see fig. 2-4),[8] and temperatures would continue to rise about 0.4 OF (0.2 'C) per decade for many decades.

Increases in the atmospheric concentrations of the greenhouse gases CH_4, N_2O, and CFCS have also been documented and can be linked to anthropogenic emissions. As the upper line in figure 2-3 shows, these gases effectively augment the greenhouse effect caused by CO_2. Sources of CH_4 emissions include rice paddies, domestic animals (cattle and sheep), natural gas production and delivery, coal production, and landfills (44). CH concentrations increased about 1 percent per year between 1978 and 1987 (from 150 to 168 parts per billion (ppb)). Recently, this increase has slowed to 0.5 percent per year; the cause of this slowdown is unknown (45).

Atmospheric concentrations of N_2O began a rapid ascent in the 1940s and increased at 0.2 to 0.3 percent per year during the mid-1980s, with current concentrations at about 310 ppb. Ice-core

[8] Given that developing countries currently use one-tenth the energy of the developed world and their usage is increasing 6 to **10 percent** per year, this later scenario is unrealistic (88).

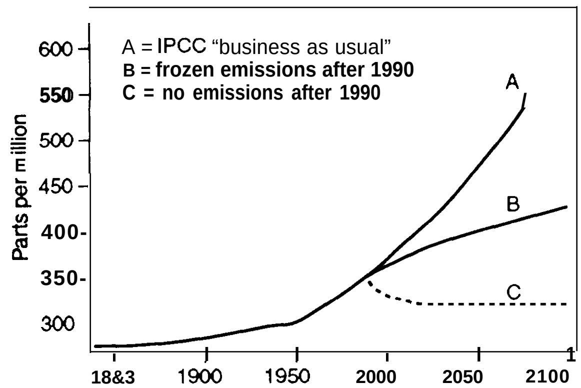
Figure 2-3-Measured and Equivalent CO_2 Concentrations in the Atmosphere



NOTE: The lower points represent atmospheric concentrations of CO_2 from Antarctic ice-core data (1890 to 1950, shown as diamonds) and from recent Mauna Loa observations (1958 to 1990, shown as stacked squares). "Equivalent CO_2 levels" are shown by the connected circles; this is the additional effect caused by various trace gases (methane, nitrous oxide, and chlorofluorocarbons) expressed in CO_2 equivalents.

SOURCE: R.C. Balling, "The Global Temperature Data," in: *Research & Exploration*, vol. 9, No. 2, Spring 1993, p. 203.

Figure 2-4-Expected CO_2 Concentrations in the Atmosphere According to Various Emissions Scenarios



SOURCE: M. Heimann, "Modeling the Global Carbon Cycle," paper presented at the First Demetra Meeting on Climate Variability and Global Change, Chianciano Therme, Italy, Oct. 28-Nov. 3, 1991.

data show preindustrial concentrations of 285 ppb, which had been relatively stable for 2,000 years. Anthropogenic sources appear to be responsible for about 30 percent of N_20 emissions[9]—primarily from nylon production, nitric acid production, and the use of nitrogenous fertilizers.[10]

CFCS are humanmade chemicals used primarily for refrigeration and insulation. A worldwide treaty (the Montreal Protocol signed in 1987 and augmented by several subsequent amendments) will eliminate use of these chemicals by the end of the century. The concentration of CFCS in the atmosphere had been increasing at 4 percent per year in the 1980s. These chemicals cause ozone depletion worldwide and the Antarctic ozone hole. Given world action to phase out CFCS, the ozone hole is expected to close in 70 years. CFCS are greenhouse gases and trap heat, but because they also destroy ozone (another greenhouse gas), the net warming from CFCS is approximately zero (45).

Temperature

IPCC predicted that global average temperature would increase at a rate of 0.5 OF (0.3 'C) per decade, amounting to a 5.4 OF (3.0 "C) increase by 2100. BOX 2-B summarizes the IPCC findings. Although the global average temperature has increased about 0.80 OF (0.45 'C) over the past 100 years, a warming of 1.4 to 4.0 OF (0.8 to 2.2 °C) is expected as an eventual result of the greenhouse gas concentration increases of the past century (this estimate does not include any warming from future emissions).

9 J. Mahlman, Director, Geophysical Fluid Dynamics Laboratory, Princeton University, personal communication, Aug. 27, 1993.

10 However, the sum of all known anthropogenic and natural sources is still insufficient to explain rates of atmospheric increase (45).

Box 2-B--Highlights of the IPCC Scientific Assessment of Climate Change

IPCC **is** certain **that:**

- There is a natural greenhouse effect that already keeps the Earth warmer than it would otherwise be.
- Emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases.

IPCC calculates with confidence that:

- Atmospheric concentrations of the long-lived gases (carbon dioxide, nitrous oxide, and the chlorofluorocarbons) adjust slowly to changes in emissions. Continued emissions of these gases at present rates, would cause increased concentrations for centuries ahead.
- The long-lived gases would require immediate reductions in emissions from human activities of over 60 percent to stabilize their concentrations at today's levels; methane would require a 15 to 20 percent reduction.
- The longer emissions continue to increase at present-day rates, the greater reductions would have to be for concentrations of greenhouse gases to stabilize at a given level.

Based on current model results, IPCC predicts that:

- Under the IPCC "business-as-usual" Scenario,[1] the global mean temperature will increase about 0.5°F(0.3°C) per decade (with an uncertainty range of O.4 to 0.9 °F per decade), reaching about 2°F (1 °C)*~t~P~~ value by 2025 and5'F (3 uC) before the end of the 21st century.
- Land surfaces wilt warm more rapidlythan the ocean, and high northern latitudes will warm more than the global mean in winter.
- Global mean sea level will rise about 2 inches (6 cm) per decade over the next century, rising about 8 inches (20 cm) by 2030 and 25 inches (65 cm) by the end of the 21st century.

All predictions are subject to many uncertainties with regard to the timing, magnitude, and regional patterns of climate change, due to incomplete understanding of:

- sources and sinks of greenhouse gases,
- clouds,
- oceans, and
- polar ice sheets.

The IPCC judgment is that:

- Global sea level has increased 4 to 8 inches (10 to 20 cm) over the past 100 years.
- Global mean surface air temperature has increased by about O.80°F (0.45 °C)(withanunoertainty range of O.5 to 1.O°F (0.3 to 0.6°C) over the past 100 years), with the five globally averaged warmest years ocourring in the 1980s.
- The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus, the observed temperature increase could be largely due to natural variability;alternatively, this variability and other human factors (such as aerosol air pollution) could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.

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1 This scenario assumes that few steps are taken to reduce greenhouse gas emissions. The atmospheric concentration of CO_2 would double (over preindustrial levels) by about 2060, but the effective CO_2 concentration (the cumulative effect of all trace gases) would double by about 2030.

SOURCES: Intergovernmental Panel on Climate Change (WCC), Climate Change: *The Scientific Assessment*, World Meteorological Organization and U.N. Environmental Program (Cambridge, England Cambridge University Press, 1890); Intergover nmental Panel on Climate Change (IPCC), *1992* /FCC *Supplement*, World Meteorological Organization and United Nations Environment Program (Cambridge, England: Cambridge University Press, 1992).

Greenhouse gas concentrations in the atmosphere will have effectively doubled[11] relative to their preindustrial values by 2030 (44, 45). Changes in global temperature will affect global patterns of air circulation and wind, possibly changing the frequency or pattern of convective storms. Some research suggests that a warmer sea surface may lead to a longer cyclone season with more-intense storms. To date, however, evidence on whether storm frequencies will change is inconclusive (81).

On the regional level, average temperatures are expected to increase more in the higher latitudes (in the Arctic and Antarctic), particularly in late fall and winter. In the northeastern part of North America under a doubled CO_2 climate, for example, warming could reach 14°F (8°C) during the winter (44), and average annual temperatures could increase as much as 18 °F (10 °C) in some high-latitude areas (81). In addition, summer warming in the middle latitudes, including much of the United States, could be greater than the global average, potentially reaching 7 to 9 °F (4 to 5 °C) in the Great Lakes area (45). In the tropics, however, temperature increases are likely to be less than the global average, and will vary less from season to season. Figure 2-5 (top) shows changes in the average annual, winter, and summer temperature ranges predicted for different regions of the United States used for studies performed for the Environmental Protection Agency (EPA) (94). Regional temperature predictions such as these are accompanied by only a medium level of confidence, but the predictions are likely to improve within the next decade (81).

Precipitation

Worldwide, average precipitation is expected to increase by 7 to 15 percent under a doubled CO_2 atmosphere. Regional changes will be much more variable, with estimated increases of 20 to 40 percent in some locations (e.g., coasts), and decreases of up to 20 percent in other areas (78, 94). The seasonal distribution and form of precipitation are likely to change. In regions where precipitation increases, a significant share of the increase may come during the winter; in some locations, more winter precipitation will come in the form of rain than snow (81). Although researchers are fairly confident about the predicted rise in average global precipitation, they are much less confident about regional precipitation because of the many uncertainties surrounding small-scale climatic processes. Figure 2-5 (bottom) shows EPA's predicted average annual, winter, and summer precipitation patterns for different regions of the United States (94).

Natural climate variability is great relative to the expected changes in climate variables. Hence, separating the signal of climate change from the noise of natural variability is difficult. One statistical analysis of climate data from the southeastern United States indicates that if average rainfall increased 10 percent, there would be only a 7 percent chance of detecting that trend after 25 years; even a 20 percent increase in rainfall could only be detected with a 65 percent probability after 50 years (63). More concretely, it is difficult to know whether the recent 6-year drought in the western United States is a rare but possible outcome of natural climate variability, an early indication of climate change, or a return to the average climate after a long particularly wet spell. Longer climate records are needed to distinguish among these various possibilities. It is unlikely that researchers will be able to resolve the uncertainties to develop better predictions for another decade or two (81).

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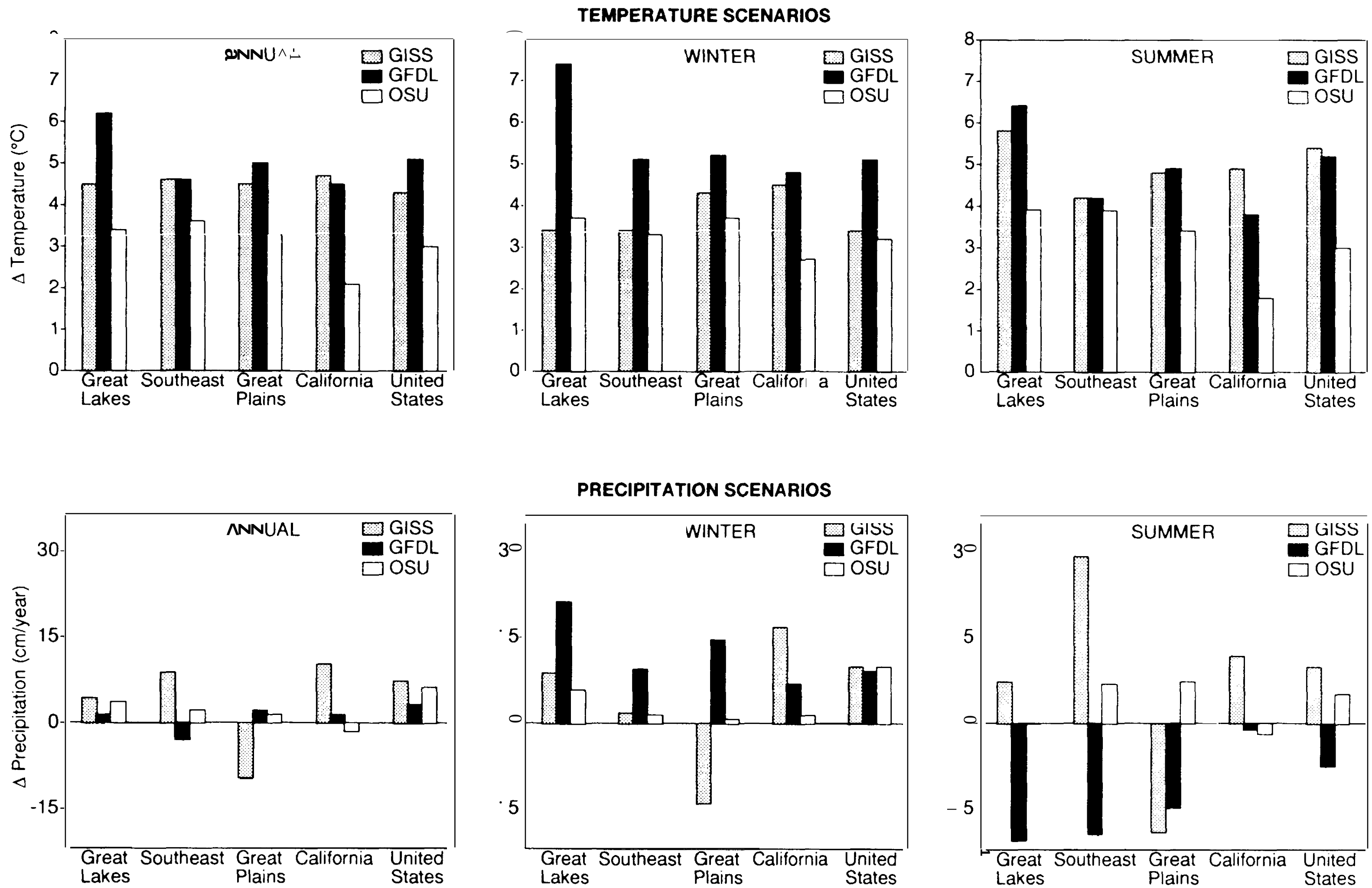
11 The equivalent doubling of CO_2 refers to the point at which the combined total of CO_2 and other greenhouse gases, such as CH_4, built up in the atmosphere have "radiative effect equivalent to doubling the preindustrial value of carbon dioxide from about 280 ppm to 560 ppm" (81). The full warming associated with that amount of greenhouse gases maybe delayed by ocean warming: "The large heat capacity of the oceans will delay realization of full equilibrium warming by perhaps many decades. This implies that any specific time when we reach an equivalent CO_2 doubling . . . the actual global temperature increase may be considerably less [than 2 to 5 'C]. However, this 'unrealized warming' will eventually occur when the climate system's thermal response catches up to the greenhouse-gas forcing. '

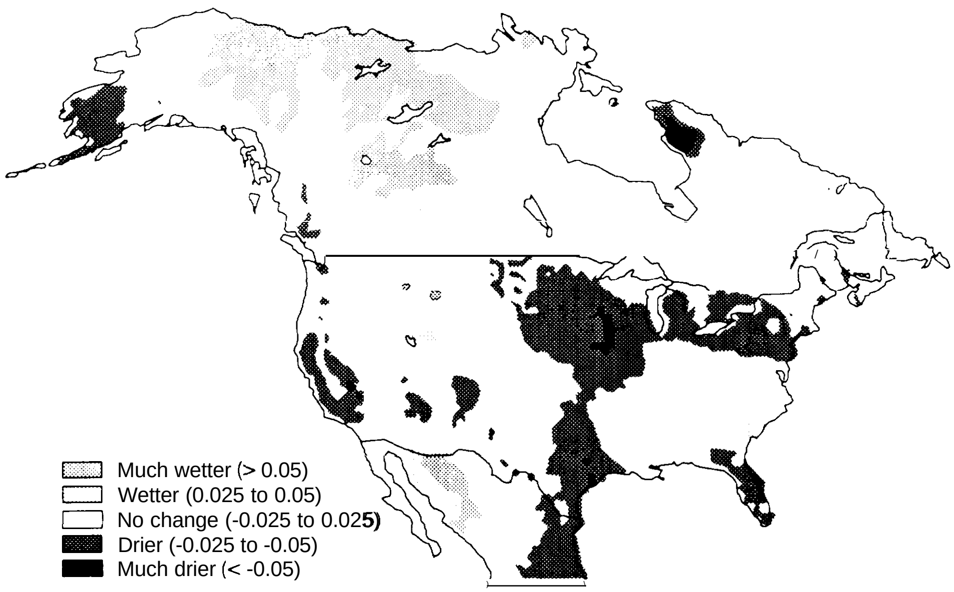
Figure 2-5—GCM-Estimated Changes in Temperature and Precipitation from a Doubling of CO_2



NOTE: GISS=Goddard Institute for Space Studies; GFDL=Geophysical Fluid Dynamics Laboratory; OSU=Oregon State University. To convert °C change to °F, multiply by 1.8; to convert centimeters to inches, multiply by 0.394.

SOURCE: U.S. Environmental Protection Agency (EPA), *The Potential Effects of Climate Change on the United States*, EPA-230-05-89-050, J.B. Smith and D. Tirpak (eds.) (Washington, DC: U.S. EPA, 1989).

Figure 2-6-Potential Soil-Moisture Changes Under the GISS Climate Change Scenario



NOTE: Numbers represent the degree of drying or wetting, calculated as the change in the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET). This ratio is an index of plant-moisture stress, indicating moisture availability relative to moisture demand. GISS=Goddard Institute for Space Studies.

SOURCE: P.N. Halpin, "Ecosystems at Risk to Potential Climate Change," contractor report prepared for the Office of Technology Assessment, June 1993.

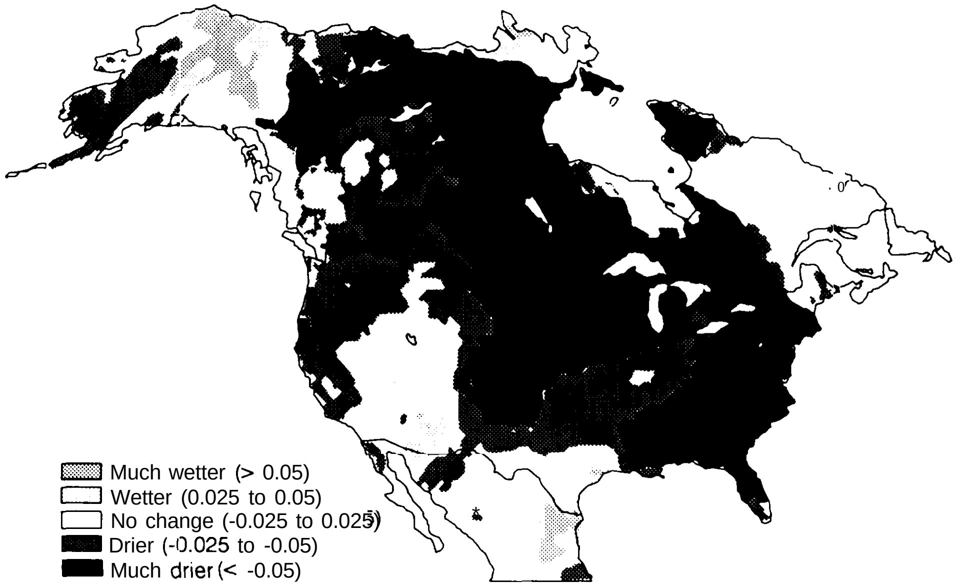
Moisture

Despite overall increases in precipitation, *soil moisture* is predicted to decrease in many mid-continental regions. Soil moisture, which is generally more important for vegetation than is total precipitation, may decrease for two reasons. First, the rate at which moisture evaporates from the soil surface and from plants (evapotranspiration) would increase as temperatures rise. The increased evaporation rates may cause soil to lose moisture at a faster rate than is supplied by the increased precipitation, particularly during the summer. Second, the manner in which added precipitation arrives can affect soil moisture by changing runoff patterns. There are limits to how much soils can absorb at once.[12] For example, sandy soils allow for relatively quick percolation of water through the soil column and into surface- and groundwater systems. However, the percolation rates of clay soils are slow. If increased precipitation comes in a few large storms rather than being evenly distributed over the year, more of it may runoff rather than remain in the soil. Thus, increases in average annual precipitation will not necessarily lead to increases in soil moisture and could be accompanied by drier conditions.

Figures 2-6 and 2-7 identify areas of the United States that may face significant changes in soil moisture based on the climate changes projected

12 The ability of soils to retain water varies considerably according to soil composition (the proportion of sand and clay the soil contains) and organic-matter content. In gene@ sandy soils with little organic material, such as those in central Florida, have a low capacity for water storage. Soils with more clay and a higher organic content, characteristic of the Midwest, can generally retain more water (13).

Figure 2-7—Potential Soil-Moisture Changes Under the GFDL Climate Change Scenario



NOTE: Numbers represent the degree of drying or wetting, calculated as the change in the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET). GFDL-Geophysical Fluid Dynamics Laboratory.

SOURCE: P.N. Halpin, "Ecosystems at Risk to Potential Climate Change," contractor report prepared for the Office of Technology Assessment, June 1993.

by two GCMS. An index of soil moisture was calculated as the ratio of available moisture to potential moisture demand (calculated as the ratio of actual evapotranspiration to potential evapotranspiration) .13 White areas in the maps indicate regions of no significant change in the moisture index, dark shading indicates areas of drying, and lighter shading shows areas that become relatively wetter. The Goddard Institute of Space Studies (GISS) scenario (fig. 2-6) produces a mixed result, with large areas of moderate drying iintermixed with patches of wetting in the Southeast and northern Rocky Mountain States. The Geophysical Fluid Dynamics Laboratory (GFDL) scenario (fig. 2-7) provides the most extreme outcome for North America, with significant drying across the eastern and central United States and along the Pacific Coast.

Sea Level

IPCC predicts that global average sea levels will rise by around 2 inches (6 cm) per decade for the next century, in contrast to the historic rate of 0.4 inches (1 cm) per decade that occurred since the end of the 19th century. By 2030, IPCC predicts that sea levels will have risen by around 8 inches (20 cm), with a total rise of 26 inches (65 cm) expected by the end of the century (44).

Sea level rise will result from the expansion that occurs as water warms. Oceans will also be

[13] Calculated for the Office of Technology Assessment by P. N. Halpin (34). *Evapotranspiration* is the loss of water from the land surface resulting from both evaporation and plant transpiration. *Potential evapotranspiration is the* amount of water that would be lost if there were never a shortage of soil moisture. *Actual evapotranspiration is the actual* amount of water released to the atmosphere (reflecting precipitation and limited availability of soil moisture).

affected by the melting of ice in polar regions. The area of sea ice and seasonal snow cover will also diminish (42). It is likely that ice on the margins will melt more quickly in warmer waters. This result could change the mix of fresh and saline waters in high-latitude seas, and could further change ocean circulation patterns.

Sea level may increase more along some coasts and less along others because sea level rise depends not only on whether the oceans are rising but also on whether adjacent land masses are rising or sinking. Some coasts are sinking as soils are compressed; others are rising due to tectonic forces or as they gradually rebound from the weight of glacial ice that burdened them during the last ice age.[14] The Mississippi River Delta in the Gulf of Mexico is subsiding, leading to relatively rapid rates of land loss, while much of the West and the Alaskan coasts are experiencing tectonic uplift and glacial rebound. Thus, the relative sea level rise and the associated land loss is predicted to be greater along the Gulf Coast (as well as in parts of Florida's Atlantic Coast and the South Atlantic States) than along the Pacific Coast. The interaction of sea level rise, altered waves and currents, and storms could lead to greatly increased erosion on sandy coasts and barrier islands (77; see vol. 1, ch. 4).

HOW WILL CLIMATE CHANGE AFFECT NATURAL RESOURCES?

Climate interacts with ecosystems at every level, from the individual to the landscape, throughout the energy and nutrient cycles, and on time scales ranging from seconds to centuries. The effect of climate can be direct, through the action of temperature, evapotranspiration, and sunlight, and indirect, through variables such as wind, cloud cover, ocean currents, and the chemical composition of the atmosphere. For example, photosynthesis rates are affected by the amount of sunlight striking a plant's leaves, which is determined by cloud cover, which in turn is determined by such climatic factors as temperature, evaporation, and wind. Similarly, global temperature affects the amount of precipitation and runoff, which in turn affects the transport of nutrients on land and through wetlands; ocean currents, which are also strongly affected by global temperatures, carry nutrients through marine systems. Indeed, over the long term, climate both shapes the physical landscape and determines where various ecosystems can exist (see fig. 2-8). Climate change of the predicted magnitude is not unprecedented, but scientists who warn of the potential harms of human-induced climate change point out that past global warming and Cooling occurred over centuries and millennia rather than decades (see fig. 2-9).[15]

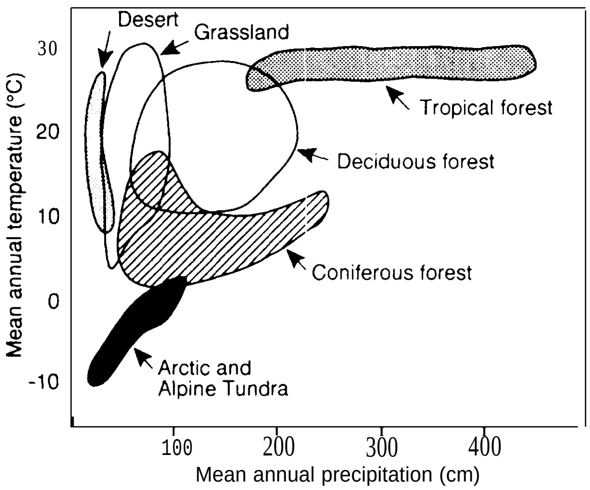
Direct Climate Impacts

Climate is often defined as the long-term "average weather. " Likewise, predictions for climate change characterize changes in the Earth's average annual temperature. However, individual plants and animals respond to events on small temporal and spatial scales. Variability is usually more important than annual totals or averages. The seasonal distribution of precipitation and temperature, the form precipitation takes (whether rain or snow), extreme events such as droughts or floods, climate-generated fire cycles, late spring frosts, and early fall freezes are all significant factors in determining the survival and productiv-

14 Land in delta areas often subsides. Sediment from upland areas loosely packs layers at the river delta where the river meets the ocean; as sediment accumulates over time, it gradually grows heavier and compresses the underlying layers, so the delta land mass sinks relative to the ocean. Coastal land may also subside in areas where offshore oil and gas extraction or pumping of water from coastal aquifers, has hollowed out underground spaces that are gradually compacted by the masses of land and water above. Much of the northern part of the North American continent is still slowly rising as it rebounds from the weight of glaciers that covered it during the last ice age and is situated on a tectonic plate that is being lifted as the adjacent plate slides beneath it; both processes may cause sea levels on the western and Alaskan coasts to appear lower relative to the coastal land mass.

15 Although recent ice-cover analysis suggests that climate may have shifted several degrees in a decade or less over regions of Greenland.

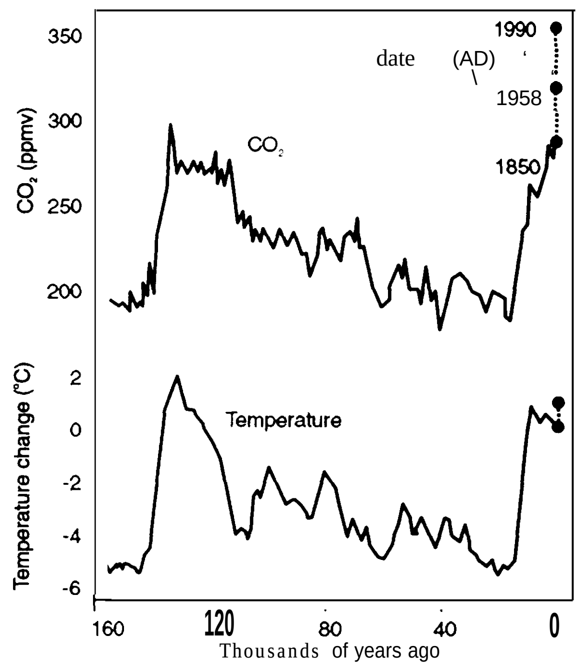
Figure 2-8-Approximate Distribution of the Major Biotic Regions



NOTE: Based on mean annual temperature and mean annual precipitation. To convert °C to oF, multiply by 1.8 and add 32; to convert centimeters to inches, multiply by 0.394.

SOURCE: Adapted from A.L. Hammond, "Ecosystem Analysis: Biome Approach to Environmental Science," *Science*, vol. 175, 1972, pp. 46-48.

Figure 2-9-Long-Term Temperature and CO_2 Records from Antarctic Ice Cores and Recent Atmospheric Measurements



NOTE: Data show that CO_2 is increasing in the atmosphere much faster than it has at any time over the past 160,000 years. The observed increase in temperature is not yet outside the range of natural variability. To convert% to oF, multiply by 1.8 and add 32.

SOURCE: C. Lorius, J. Jouzel, D. Raynaud, J. Hansen, and H. Le Treut, "The ice-Core Record: Climate Sensitivity and Future Greenhouse Warming," Nature, vol. 347,1990, pp. 139-145,

ity of individual organisms. One or several extreme events (such as a hurricane or drought) may shape ecosystem boundaries more than many years of "average" weather. Eventually, however, when the ''average' has shifted well beyond "normal," ecosystems may have trouble Persisting.[16]

The Role of *Temperature*

Temperature and its distribution are important determinants of plant productivity and survival. Temperature range exerts three classes of effects on plants: 1) low temperatures can damage plant tissues, causing die-offs during unusual extreme events and controlling the northward or altitudinal migration of plants; 2) in intermediate ranges, temperature governs the rates of photosynthesis, respiration, the growth and development of seeds, and other processes; and 3) high temperatures may stress plants to the limits of their ability to withstand heat and moisture loss, thus controlling plant distribution and migration (19). Seasonal distribution, diurnal cycles (i.e., the variation from night to day),[17] and the occurrence and timing of extremes (e.g., late spring frosts, early winter storms, and peak summer high and winter low temperatures) are all aspects of the effects of

16 A shift upward in the mean temperature (with an unchanged standard deviation) will make heat waves Of today more ''average'' in the future.

17 A longer growing season based on temperature may actually prove beneficial for some plants because day length is a major factor in productivity.

Box 2-C-Climate Change and Coastal Fisheries

Background

The U.S. commercial, recreational, and sport fishing industries, worth an estimated $14 billion in **1986** (73), rely on the health of nearshore and coastal areas (such as tidal marshes, coral reefs, seagrass beds, mangrove forests, estuaries, and banks). Two-thirds of the world's fish catch, and many other marine species, depend on coastal wetlands and estuaries for their survival **(42).** By far the greatest portion of U.S. commercial fisheries catches, with the exception of those from Alaskan fisheries, are composed of estuarine-dependent species. Ongoing alterations of critical habitat (such as geographic fragmentation and pollution) may be exacerbated by climate change.

Much is yet to be learned about the marine environment and the long-term effects that humans have on it. Understanding the breadth of environmental stresses that affect fish and coastal systems will be essential to forecasting how climate change may affect these valuable areas. During the 1970s and 1980s, populations of many commercially important estuarine-dependent fish plummeted. Human activities in the coastal zone are thought to have been responsible for many of the dramatic declines in fish populations. Overfishing has been implicated as a primary cause of the declines of some fish stocks, with some 42 percent of species in American waters considered to be overfished (52). The Atlantic cod fishery of the Grand Banks area has all but collapsed, triggering industry-related layoffs (primarily in Canada) of more than 30,000 people (75). Migratory species such as salmon, shad, herring, and striped bass have decreased due to a combination of habitat degradation and overfishing. The Chesapeake Bay's oyster harvest has declined 96 percent from the levels of 100 years ago due to disease, over-exploitation, predators, and habitat degradation (18). Nearly half of the Chesapeake's wetlands and seagrass meadows, which serve as primary nursery habitat for many migratory species, have been destroyed. Such destruction will adversely affect future fish populations.

The fishing industry from Southern California to Alaska is experiencing similar troubles as a result of overfishing, the damming of spawning rivers, water-quality degradation from logging, and other anthropogenic

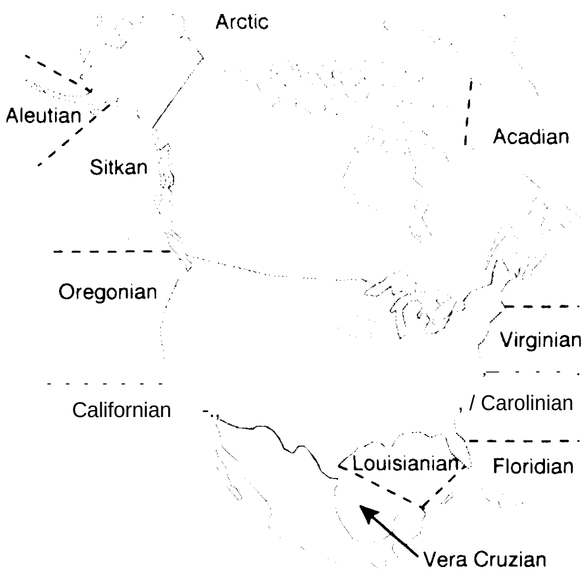
(Continued on next page)

temperature on plants. Length of the growing season is also very important, particularly for agricultural crops. Seed production generally requires a certain number of days with a temperature above freezing, often expressed in terms of degree-days. At northern latitudes, the growing season may not be long enough for some species to set seeds. Longer growing seasons in a warmer climate could boost productivity of trees and other plants, especially those that could tolerate erratic spring and fall weather (e.g., early or late frosts). Seeds of many tree species, including conifers, need to be chilled for particular periods before they will germinate (17, 21), so a shortened cool season could be detrimental to such species.

In addition to the numerous effects of temperature on vegetation, temperature exerts other direct and indirect influences on animals. Higher-than-usual temperatures can adversely affect the reproductive success of many birds, mammals, and insects (26). Increased water temperature limits the availability of oxygen in the water and, in turn, reduces the amount of oxygen available to fish and other aquatic organisms (87). For many fish species, ambient water temperature is critical for survival (see box 2-C). In addition, temperature increases can actually reduce the number of species in a given ecological community (87), though total biomass may increase.

Warmer temperatures could allow some insects, including various agricultural pests, to survive winters farther north than they now do. For example, the potato leafhopper, which is a pest on soybeans and other crops, now overwin-

Box 2-G-Climate Change and Coastal Fisheries--(Continued)



activities. In Alaska,where the seafood industry employs 23 percent of the State's work force, this could prove to be a major problem. More than half of the Nation's seafood harvest comes from Alaskan waters.

Scientists have hypothesized that climate warming is likely to alter the distribution and reproductive success of coastal species (77). Many marine species are sensitive to narrow temperature variations. Water temperature controls the respiration and reproduction rates of fish. Changes in temperature can also affect the geographical distribution of species range because some species will thrive in warm waters, while others function effectively only in coder waters. Changes in stream flows will also be important because they can alter the salinity of coastal bays and estuaries. The interactions of temperature and salinity determine the "tolerance zone" for most fish species. Anadromous fishes--which swim upstream to spawn, such as salmon--also depend heavily on stream flow and water quality *(33)*. If these are altered by climate change, there maybe serious effects on reproductive successin ail these cases, climate change would be expected to alter the dose associations between species distributions and reproductive success, and the success of the fishery as a whole. Although it is difficult to estimate the magnitude of these changes, impacts could upset the stability of the commercial fishing industry on which many coastal residents rely.

Coastal areas have also been affected by human activities that contribute toxic pollutants and polluted run-off to marine waters. Runoff from developed and agricultural areas and overflow from storm-water systems adversely impact these areas. Nutrients cause algal blooms, which deplete oxygen available for fish and other organisms. Stressed species may become more susceptible to disease and predators. Shoreline construction and dams have also contributed to fishery population declines. Destruction of estuarine and coastal zones limits nursery and breeding areas, and dams prohibit fish from reaching upriver spawning grounds (see vol. 1, ch. 4, and vol. 2, ch. 4).

Regulatory attention has generally not addressed coastal zone management in light of the potential impacts of climate change. Harvest regulations, which are either inadequate or insufficiently enforced, seem unable to keep pace with the decline in fish populations (52). In she@ too many fishermen are taking too many fish from overburdened ecosystems. Traditional fishery management is concerned primarily with a few major resources and tends to pay far less attention to the other ecosystem elements that fish depend on (77). Increasing concerns about ecosystem management (see vol. 2, ch. 5) and the upcoming reauthorization of the Magnuson Fishery Conservation and Management Act (P.L 94-265, as amended) and the Clean Water Act (P.L 92-500, as amended) offer opportunities to work toward improving fisheries and their habitat. Below, we highlight the regional importance of marine fisheries and identify particular problems (77).

Regional Characteristics of the U.S. Coastal Marine Fisheries

Acadian-Boreal (Newfoundland and southern Greenland to Cape Cod, MA)

- Cultural: Indigenous coastal people-New England dam diggers.
- Fishing:
  —7 percent of the Nation's commercial fisheries
  --estimated value, $250 million in 1990
  --multispecies trawl fishery
  --32 percent of species estuarine-dependent
  -important species include hard dam, soft dam, American lobster, sea scallops, northern shrimp, Atlantic cod, butterfish, cusk, flounder, haddock, red and white hake (sliver hake)
  –Atlantic cod most commercially important fish in 1989 (valued at $45 million)
- ***Common problems:***
  -only remaining self-supporting U.S. salmon runs are in Maine
  -lobsters are overharvested
  -northern shrimp are at maximum harvest and subject to environmental variability, especially when waters are warmer

Virginian-Mid Atlantic (Cape Cod, MA, to Cape Hatteras, NC)

- Cultural:Indigenous coastal people--Chesapeake Bay watermen.
- ***Fishing:***
  --estimated value, $500 million in 1990
  —11 percent of the Nation's commercial fisheries
  -most important species are blue crab and surf and ocean quahog
  -Chesapeake Bay fish: 87 percent are estuarine-dependent
- ***Common problems:***
  -region 'is the most urbanized and densely populated in the United States
  --disease, overharvesting, predation, and pollution are rampant--responsible for reductions in harvestable shellfish, forcing many watermen out of business
  --second to the Gulf of Mexico in the number of point sources of pollution
  --striped bass began a precipitous decline in 1973

Carolinian-south Atlantic (Cape Hatteras, NC, to Cape Canaveral, FL)

- Fishing:
  -3 percent of the Nation's commercial fisheries
  -estimated valued, $169 million in 1990
  -94 percent of species estuarine-dependent
  -over half of this harvest from estuarine-dependent species
  -most important species include Atlantic menhaden, blue crabs, and penaeid shrimp
- ***Common problems:***
  -application of pesticides and fertilizers to extensive commercially harvested forested wetlands
  degradation of shellfish habitat due to agricultural runoff and septic system overflow

Floridian-West Indian (Cape Canaveral to Key West, FL, and West Indies)

- ***Fishing:***
  -values for individual species are not observed
  -important species include the Queen conch, spiny lobster, Nassau grouper, and more than 100 reef fishes

(Continued on *next page)*

Box 2-C--Climate Change and Coastal Fisheries--(Continued)

■ *Common problems:*

--*growing human populations,* greater demands, and technological improvements in catch
-virtually all assessed reef-fish stocks are overharvested
--major tropical storms, including hurricanes, generally affect the area

Louisiana-Gulf of Mexico (Northern Gulf of Mexico from Central West Florida to South Texas)

● Fishing:

—17 percent of the Nation's commercial fishery (with Vera Cruzian)
--estimated value, $648 million in 1989
--leading seafood producer among regions

■ Common *problems:*

--*subject to* devastating *floods,* tornadoes, hurricanes and tropical storms, erosion, land subsidence, saltwater encroachment, and sedimentation
--second-fastest-growing population rate of all regions
-more point sources of pollution than any other region
-application of pesticides to agricultural lands is the highest among all regions

Vera Cruzian-West Indian (South Texas **to Yucatan Peninsula)**

■ Fishing:

--fourth leading U.S. port in fisheries value
-major **commercial species** are similar to those of the Gulf **region**

■ *Common problems:*

-hurricanes and intense thunderstorms

California-subtropical Eastern Pacific (Southern California(LosAngeles basin) southwardto Mexico and Central America)

■ Fishing:

-**major** commercial species include Pacific sardine, northern anchovies, and Jack mackerel

■ *Common problems:*

-*most wetlands* already lost; restoration doubtful
-low-lying coastal areas subject to sea level rise

Oregonian-Temperate Eastern Pacific (California north of Los Angeles to British Columbia)

■ *Fishing:*

-**estimated value,** $337 million in 1989
-ens-fifth of catch estuarine-dependent species, especially Pacific salmon (Chinook, coho, sockeye, pink and chum)
--commercial landings of salmon valued at $140 million
-other **important species** include northern anchovies, Pacific sardine, Jack mackerel, **and groundfish** (flatfishes, rockfish, including Pacific whiting, sable fish, Dover sole, widow reddish, and others)

■ *Common problems:*

--confiicts among fishermen, the **Fisheries Council, various States, Canada and foreign fisheries regarding the allocation of resources**
-**worsening freshwater (spawning) habitat** has been the **main cause of the salmon decline, and** wild coho stocks of the lower Columbia River were recently declared extinct

Sitkan-North Pacific (British Columbia to base of Alaska Peninsula)

■ *Fishing:*

--*56 percent* of the Nation's commercial landings of fish (with other Alaskan fisheries)

--estimated value, $1.5 billion in 1990
-5.4 billion pounds (2.5 billion kg) landed In 1990 (with other Alaskan fisheries)
—76 percent of species estuarine-dependent
--most important species include Pacific salmon, Pacific herring, Pacific halibut, Gulf groundfish (Pacific cod, stablefish), king crab, and tanner crabs

- Common problems:
  -some rookeries threatened by fishery operations
  -Exxon Valdez oil spill severely contaminated coastal areas

Arctic-Boraal/Arctic (Southeast Bering Sea to Chukchl **and Beaufort Seas and Canadian archipelago)**

- *Cultural:Coastal* indigenous people--Eskimo, Aleute
- ***fishing:***
  -most important species include Pacific salmon, Alaska pollock, Pacific herring
  —Pacific salmon fisheries rank as the State's largest nongovernmental employer
  -provides an integral part of Alaska's native culture and heritage
- Common problems:
  -acme stocks (chinook and echo) may be harmed by foreign **high-seas** catches, and some salmon may be regionally overfished
  -destruction of spawning and rearing habitat
  -human population in this area is expected to increase by 380 percent between 1960 and 2010

Aleutian-North Pacific (Alaska Peninsula base to Aleutian and **Pribilof Islands and Including southwest Bering Sea)**

- ***Fishing:***
  -estimated value of groundfish, $352 million in 1990
  -dominant groundfish groups are walleye pollock, flatfishes (Yellow sole, rocksole, other), Pacific cod, Atka mackerel, and shrimp
  —Alaska king crab value, $88 million in 1990
- Common problems:
  --The U.S. fishery for shrimp in Alaska is **at a low level, and potential yields are not well-understood (91)**

Insular-Indo Pacific (Tropical Indian and Pacific **Oceans;** not shown **in** figure)

- *Cultural:* Coastal indigenous people--Papuan, Micronesia, and Hawaiian
- *Fishing:*
  —7 percent of the Nation's commercial flsheries taken in the Pacific United States and ***Hawaii***
  -major species include invertebrates species (spiny and slipper lobsters; gold, bamboo and pink corals), bottom fish (snappers, jacks, groupers, Pacific armorhead), tropical tunas (yellowfin and skipjack), and albacore
- ***Common problems:***
  -coastal pollution
  -destructive fishery technologies (explosives, poison, etc.)
  --overfishing by foreign fleets
  --ambiguous application of Federal environmental laws

SOURCES: M.R. Chambers, 'U.S. Coastal Habitat Degradation and Fishery Declines, " in: Transactions of the North American Wildlife and natural Resources Conference (Washington, DC: The Wildlife **Management Institute, In press); U.S. Department of Commerce, National Oceanic and Atmospheric** Administration (NOAA) **National Marine Fisheries Service (NMFS), Our Living Oceans, The First Annual report on the Status of the U.S. Living Marine Resources, NOAA Technical Memo, NMFS-F/SPO-1, 1991; C.G. Ray, G. McCormick-Ray,** and F.M. Potter, Global *Climate Change* and the Coastal Zone: *Evaluation* **of Impacts on Marine Fisheries and Biodiversityof the** *U.S., contractor* report **prepared for the Office of Technology Assessment, 1993.**

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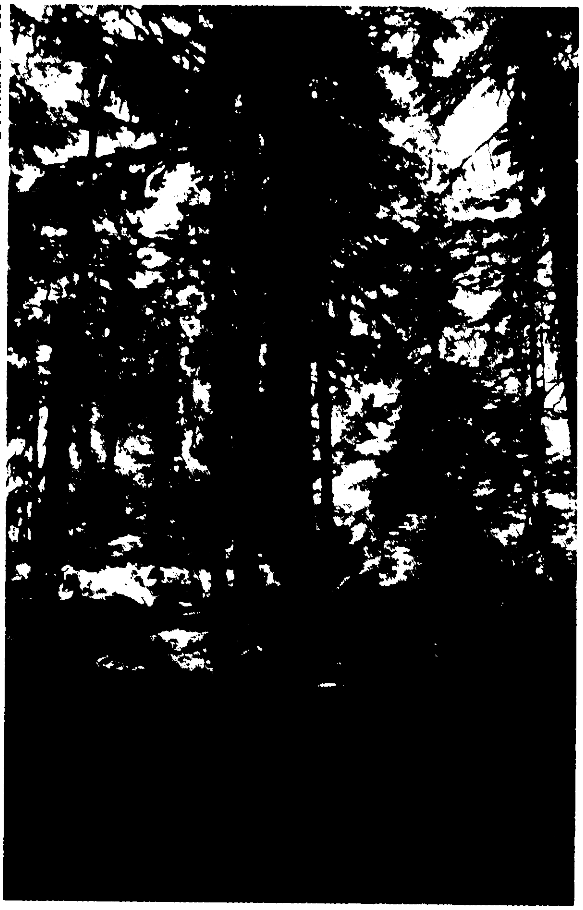

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The Ro e o Precip a on and So Mois ure

Pre ıp tati n—or mo pre y oil mo ture (the result of a combination of precipitation, infiltration, runoff, and evaporation)--directly affects plant growth through its role in photosynthesis. Although average annual precipitation is often used to characterize climate zones, the seasonal distribution is more significant than the annual total. Adequate moisture during the growing season is critical. Seeds need moisture to germinate, and young plants-both annuals and perennials--are often quite sensitive to drought. Vegetation may respond by defoliating, which reduces water and nutrient demand, helping plants survive dry periods. Precipitation during the growing season controls wood growth as well as the size and maturation time of seeds (21, 42). Decreases in soil moisture can slow growth, interfere with reproduction, and cause plants to die early. Increases in soil moisture are less likely to cause harm unless the soil in normally dry areas becomes saturated with water for extended periods. Standing water can drown the roots of plants not adapted to wetlands by interfering with normal respiration; extended saturation of roots may kill the entire plant.

Direct effects of moisture on many land animals may often be less important than the indirect effects-that is, moisture affects plant growth, which then affects the availability of food and habitat (86). However, moisture does play a critical, direct role in the natural history of invertebrate species (e.g., snails) and is essential to the survival and reproduction of amphibians (105). Fish and other aquatic organisms that inhabit rivers and streams can be threatened by either too little water during drought periods or too much runoff flowing into streams. During periods of high precipitation, water may become turbid, interfering with the health and functioning of the aquatic ecosystem. Moisture is also important to many microorganisms and fungi, including many that contribute to human disease or are considered forest or agricultural pests (described in more detail below and in vol. 1, ch. 6, and vol. 2, ch. 6).

Sunlight

The amount of available sunlight, or *solar irradiance,* that strikes vegetation is an important variable in photosynthesis and productivity. Individual plants or species that make up the canopy, those near the edges, or those growing in clearings receive more light, whereas those in the understory are better adapted to lower light levels. Solar irradiance varies regularly from season to season and from latitude to latitude. Cloud cover also affects the quality and quantity of solar irradiance and its distribution over time, allowing less sunlight to reach the surface on cloudy days. If climate change is accompanied by increased cloudiness, as some models predict, overall plant productivity could decline. Water stress and high temperatures may also affect plant response; however, plant response to changes in solar irradiance is complex and difficult to predict (19).

In addition to the total amount of solar irradiance, the number of hours of sunlight per day (day length, or *photoperiod)* plays a role in plant functions such as flowering and the setting of fruit, and influences the rising of sap indeciduous trees, such as sugar maple, in spring. Light quality may also affect productivity. For example, cotton depends on very regular day lengths, which only occur in southern latitudes. Plant species that might migrate northward as the climate warms may not be able to reproduce as effectively because day length is longer at northern latitudes during the summer and drastically reduced during the winter (41). On the other hand, adaptation to a shorter photoperiod may limit northward movement.

Increased $C0_2$

Rising concentrations of atmospheric CO_2 may affect the rates at which plants grow, respire, use water, and set seeds. This is known as the CO_2 *fertilization effect (see* box 2-D). Numerous laboratory experiments and intensively managed agricultural systems that have been studied suggest that CO_2 has the potential to boost plant growth and productivity by speeding the rate of photosynthesis, relieving nutrient stress (by improving efficiency of nutrient uptake and use), increasing water-use efficiency, decreasing respiration (which is a major source of water loss), slowing the rate at which leaves die, and speeding the development of seeds (27, 42,66,68,69, 93).

Theoretically, the fertilization effect could compensate for the water stress faced by plants in areas that become warmer and drier due to climate change, and might actually increase the total global biomass (41). On the other hand, various studies have suggested that in some settings, there may be limits to and even detrimental effects from increased CO_2. For example, changes in the amount of carbon in plant leaves affect nutritional quality (65), which could mean that foraging animals would have to eat more leaves to gain the same amount of nutrition. Increased CO_2 may also cause starch to accumulate in plant leaves to such high concentrations that it could actually harm the plant by interfering with photosynthesis (50), though there is no field data to support this.

Numerous complex factors interact to determine the extent to which fertilization actually occurs in natural ecosystems, and many uncertainties about the overall impacts remain. Plant responses to CO_2 vary according to species and stage of development, as well as to water and nutrient availability (42). Some plant species already use CO_2 efficiently and will not receive much of a boost, whereas other species are now limited by their inefficient use of CO_2 and could profit from higher atmospheric concentrations.

Plants may experience the greatest productivity boosts from increased CO_2 when other nutrients are plentiful (7). Thus, for example, field studies have demonstrated that higher CO_2 concentrations boost productivity in Chesapeake Bay salt marshes, where water entering the bay is rich in nutrients (2, 27, 28, 107), but CO_2 fertilization does not appear to be significant or permanent in nutrient-limited tundra and other arctic ecosystems (32, 68). Few other ecosystem types have yet been tested in the field. Intensively managed agricultural systems, in which nutrient deficien-

Box 24)-Coping with Increased CO_2: Effects on Ecosystem Productivity

Climate,particularly the combination of temperature and moisture, largely determines where plants grow (14), and vegetation, in turn, is key to the distribution of animal species. Generally, climate belts vary within the United States from humid and damp in the Southeast and Northeast to moderately dry in the central regions, to arid in much of the West, except for a humid belt along the Pacific Coast from northern California to Washington. Temperature and precipitation maps of the United States reveal bands across the Nation from north to south for temperature, and east to west for precipitation. Vegetation growth, in type and lushness, varies with temperature and altitude, but in all cases, solar irradiance is critical to the productivity of living things.

The sun provides the energy that fuels ecosystems; this energy is transformed through the processes of photosynthesis and photorespiration. During *photosynthesis,* plants use water and the energy from sunlight to convert carbon dioxide (CO_2) and other nutrients into organic matter and oxygen. This process is dependent on the concentration of CO_2 in the air (i.e., ambient CO_2), and, therefore, changes in normal CO_2 levels may affect photosynthesis and, likewise, plant growth. External environmental factors, such as temperature and the availability of nutrients, may modify photosynthesis as well. The output of organic matter by an ecosystem is characterized as its *biological,* or *primary,* productivity. Linked to primary productivity is *nutrient cycling--the* absorption by plants of vital nutrients (e.g., carbon, nitrogen, and phosphorous) and their subsequent conversion into usable forms.[1] The combination of energy and nutrient cycling in vegetative systems determines the nature of the assemblage of plants and animals in a given area Certain types of plants, growing in certain conditions, have higher primary productivities than others, Ecosystems that are highly productive often support both large numbers of other organisms and many diverse species-that is, they are characterized by high *secondary productivityand* high biodiversity.[2] Productivity is also key to *carrying capacity* --the number of organisms that a particular area can support. Carrying capacity can vary from year to year based on many factors, including climate,

1 Carbon is derived from CO_2 through photorespiration; nitrogen and phosphorous are taken up from the soil and converted to usable forms during the same process.

2 Although definitions vary, biodiversity generally refers to the "variety and variability among living organisms and the ecological complexes in which they occur" (89).

cies can be remedied by adding fertilizers, may be more likely to receive a productivity boost from additional $C0_2$ than are natural ecosystems. Many complex interactions determine to what extent, if any, the $C0_2$ fertilization effect documented in laboratory studies will occur in natural ecosystems. The responses will likely vary so much from ecosystem to ecosystem and location to location that there cannot be a simple answer to the question of whether it will present a net benefit or a net harm.

■ Indirect Climate Impacts Through Stressors

Climate will also have numerous secondary impacts. Increases in herbivores, disease, and fires, which play an important and visible role in mediating the near-term effects of climate change on communities and ecosystems, could result. For example, although few trees in a forest may die outright due to heat or drought, it is likely that many trees will sicken and become more susceptible to insects and disease. At the same time, trees in decline will provide more fuel for frees (83). The extent to which an area is stressed by anthropogenic activities, such as land clearing and pollution, will also influence the effects of climate change.

Insects and Disease

Climate may affect the proliferation of insects and disease in numerous ways. Higher temperaand refers to the individual species or mix of species in a particular ecosystem. Overall, however, ecosystem health and productivity is dependent on the availability of sunlight, water, nutrients, and CO_2.

Considerable experimental evidence has shown that an increase in the atmospheric concentration of CO_2 has the potential to increase plant growth and ecosystem productivity (28). This expected effect of increased plant productivity in the presence of elevated CO_2 concentrations is known as the "CO_2 fertilization effect," and it is expected to be particularly pronounced in the presence of plentiful supplies of light, water, and nutrients. Over the long run, this effect may help alleviate the rate of global warming by drawing excess CO_2 from the atmosphere (8), although researchers are uncertain about the extent to which this will occur (vol. 2, see box 6-B).

Plants vary in their response to CO_2 in part because of differing photosynthetic mechanisms--most species follow the C_3 pathway and some, the C_4 pathway. C_3 species (e.g., wheat, rice, soybeans, and all woody plants) are not yet fully saturated with CO_2 and may greatly increase their productivity, whereas C_4 species (e.g., corn, sorghum, sugar cane, and tropical grasses) are almost saturated with CO_2 and their productivity may not be much affected. Added productivity of C_4 species from doubled CO_2 may be in the O to 20 percent range, and in the 20 to 60 percent range for C_3 species. The differential effects of CO_2 could alter the dynamics of competition among species, with C_3 plants potentially prospering at the expense of C_4 species. In agriculture, this competition among plants may prove important. Because 14 of the world's most troublesome weed species are C, plants that occur amidst C_3 crops, enhanced CO_2 concentrations may make such weeds less competitive (73). However, many of the major weeds of corn (a C_4 crop) in the United States are C_3 plants; climate change may favor the growth of these weeds. Similarly, natural grassland ecosystems where C_4 grasses now dominate may be **invaded by weedy** plants. Competitive success, however, does not depend solely on response to CO_2. Competition among species in natural ecosystems will continue to depend on the ability of species to tolerate soil, light, temperature, and moisture conditions. Because of the complex effects of competition among species, it is by no means clear how the overall productivity of natural ecosystems will increase under elevated CO_2 (8).

SOURCES: B.G. Drake, "The Impact of Rising CO_2 on Ecosystem Production," Water, *Air, and Soil Pollution,* vol. 64,1992, pp. 25-44; P.M. Kareiva, J.G. Kingsolver, and R.B. Huey (ads.), *Biotic Interactions and Global Change* (Sunderland, MA: Sinauer Associates, Inc., 1993).

tures could accelerate the growth rate of insects. If the number of warm days per year increases, the number of insect generations per year may increase. Also, the range of many insects is determined by cold winter temperatures. As described in the section above on temperature impacts, milder winters could allow insects such as leafhoppers (agricultural pests) to spread north of their present range. Hot, dry conditions encourage the growth of numerous fungi in forests (such as *Armillaria mellea,* a fungus that causes root disease), which can cause widespread damage in many types of forests. Warm, humid conditions, which favor soil and leaf-litter organisms as well as decomposition, may encourage the growth of other fungi and insect pests, such as aphids, which can also be quite damaging,

Once stressed by heat or drought, vegetation may become more susceptible to pests (58). Changes in CO_2 concentration may affect the composition of leaves, potentially making them less nutritious, so insects might have to consume more to obtain the same amount of nutrients (8). Thus, damage from insects and disease might increase, and in some cases, the effects of climate change may become noticeable over the short term. Over the long term, damage from insects and disease may cause less-adaptable species to decline, potentially opening the way for exotic species to migrate into communities (21, 83).

Extreme Events

Periodic but unpredictable events such as extended drought, storms, and fire are among the primary natural factors that shape ecosystems.

Severe storms accompanied by high winds and rain, hail, or ice may cause significant wind damage in forests, toppling older trees and leaving a trail of debris, but also clearing space for new vegetation to take root (see vol. 2, ch. 6). Storm damage may reduce habitat for birds and wildlife that prefer a dense forest canopy and little undergrowth, but could increase food and habitat for animals that thrive in mixed forests with cleared areas, such as deer. In coastal areas, tropical storms and their accompanying high winds and waves play an enormous role in coastal processes (see vol. 1, ch. 4).

The occurrence of fire is critical in determining vegetation types, successional history, and wildlife species in forests in more arid areas, such as prairie and chaparral, and in wetlands. Fire is important in maintaining prairie, but the control of fire has virtually eliminated most naturally occurring prairie areas. In some wetlands, including the Okefenokee Swamp and others along the Atlantic coastal plain, fire has played an important role in clearing shrubby growth and maintaining wetland vegetation. Under normal conditions, fire clears out forest undergrowth, damaging some trees but allowing new ones to take root, thus creating a more open stand of trees (see vol. 2, box 5-I).

Fire has been recognized for playing an important role in vegetation succession. In areas where fires have been suppressed and fuels have accumulated, however, fires may become so hot that they cause severe damage, and forests may regenerate slowly or not at all. For example, chaparral ecosystems in the foothills of California rely on fire to spur the growth of the shrubby plants that dominate the area; however, in areas where fire has been suppressed, a fire that does occur will be more damaging, and the regeneration of chaparral species maybe affected. Natural fire regimes are influenced by the frequency of lightning (which may or may not increase as the climate changes), the presence of hot, dry winds to carry a fire once ignited, and an abundance of dry fuel provided by the buildup of undergrowth or vegetation that has died from drought or disease, as well as by dry, living vegetation (22). Fires may increase under changed conditions, but the ability of species to regenerate in areas with less moisture, because of climate change, maybe reduced. Thus, recovery may not occur.

Anthropogenic Forces

Climate change may serve to make species or ecosystems more susceptible to stresses from human disturbance. Human activities have become so widespread that they are now a pervasive influence on much of the environment. Agriculture, timber harvesting, road building, and urban development have fragmented the landscape, carving natural areas into ever smaller and less-connected patches (see vol. 2, box 5-E). This fragmented landscape may offer few opportunities for organisms to adapt to a changing climate. Fragmentation often isolates small populations of plants and animals, which may limit genetic diversity and make them less able to adapt to change over time. These small, isolated populations may also be prevented from moving to new and more favorable areas by barriers such as roads, buildings, or large cultivated fields. In addition, humans may respond to changes in climate by adopting land uses (such as more extensive cultivation) that further fragment the landscape, exacerbating the stresses on flora and fauna.

Human activities may also result in the intoduction of weedy and nonindigenous species that flourish in the disturbed areas and that may eventually outcompete other species, leading to local extinctions and reducing the diversity of ecosystems. In areas where weedy or nonindigenous species already pose a threat to a particular species or ecosystem, the added stress of climate change may further tip the balance in favor of weedy species that thrive in disturbed conditions. Similarly, air pollution in urban areas, and in much of the Northeast, already threatens the health of many plant species. Climate change could further weaken individuals that are already stressed by pollution, and could make them more susceptible to insects or diseases.

Although climate change might not be the proximate cause of ecosystem harm, it could increase the potential for damage. In sum, climate change may exacerbate many other stresses, both natural and anthropogenic.

Direct Climate Impacts on Ecosystems

As temperature and moisture regimes change, climatic zones could shift several hundred miles toward the poles, requiring plants and animals either to migrate or adapt to a new climate regime. The rate of change will determine the degree of impacts: some species might be able to keep up with change, others could become extinct-either locally or globally (see box 2-E). The ability of a species to adapt will be critical to its survival. By the same token, the decline and disappearance of species that are unable to adapt will decrease the biodiversity of ecological communities. Such a reduction may leave the remaining species more vulnerable to catastrophic events. Ecosystems, the assemblages of plants and animals, are unlikely to move as units, but will instead develop new structures as species abundance and distribution are altered (42).

The general distribution of ecosystems is related to climatic conditions. The Holdridge life zones shown in figure 2-10 characterize regions of North America according to the general vegetative ecosystem suited to current climate conditions. Under climate change scenarios projected by four GCMS, this distribution of vegetation zones will shift significantly (34). There is general agreement among scenarios about the direction of change: the extent of tundra and cold-desert climate zones will decrease, and the area of potential forest and grasslands will increase. Despite this general agreement, there are qualitative differences, with dry forest types increasing under some climate scenarios, and moister forests increasing under others. Overall, as much 80 percent of the land in the United States may shift to anew vegetation zone (see fig. 2-11). Associated with such shifts in climatic zones could be large-scale disturbances to existing ecosystems.


D. DOWNING © 1993

Alpine areas are awash in color when spring and summer flowers bloom.

Adjustment of Species

Natural adjustments to climate change could begin with the failure of some species to reproduce because flowering, fruiting, and seed germination-and in some animals, reproductive physiology or mating behavior--could be affected. All of those processes are particularly sensitive to climate. Reproductive failure might allow new species to invade, or give a competitive advantage to other species already present. Thus, a gradual adjustment could occur, although in

Box 2-E--Responses of Natural Systems to Climate Stress: Adaptation, Migration, and Decline

Resonses of individuals and communities to climate stress fall into three basic categories: adaptation, migration, and decline and die-back The extent to which individuals and communities respond may depend on the rate and magnitude of climate change.

Adaptation

It is difficult to predict which species, populations, communities, ecosystems, and landscapes will prove most able to cope with climate change because of the many variables and uncertainties that exist. However, biological diversity affords populations the ability to adapt to changes in the environment by serving as a natural protection against shocks and stress."The rule that there is security in diversity is an axiom of ecology as well as finance.... Biological diversity is a natural protection against surprises and shocks, climatic and otherwise. Among diverse species will be some adapted to prosper in a new landscape in new circumstances" (21).

in species with diverse gene pods, the chances will be greater that some individuals will possess a combination of genes that is useful in new environments, such as genes that determine drought resistance and tolerance to extreme temperatures or salinity. These individuals will be the most likely to survive and pass along adaptive characteristics to their offspring. At the community level, diversity may also increase the chances for survival. For example, a forest stand composed of a single species or of trees that are all the same age may be less able to withstand climate change than a forest composed of several species within a range of ages. Biodiversityis generallyconsidered an important trait at the ecosystem level, too, because it increases the chances that the overall structure and function of an ecosystem will persist or adapt to changing conditions, even if some species that were formerlypart of the ecosystem no longer remain (21).

Some species may prosper under climate change conditions, others may be able to adapt relativiely quickly, and still others may prove unable to adapt at all and may face extinction. As a result, ecosystems may change as differed plant species become dominant and different animal species become associated with altered habitats (21). Species in varied landscapes maybeable to find microclimates within their current ranges that are suitable, and some species may even thrive and expand their ranges. Species already adapted to disturbed environments (e.g.,weedy species) may be particularly resilien to changes in climate. On the other hand, species with extremely specific and/or narrow habitats maybe more at risk to changes in climate. In addition, species on the fringe of habitats, in transitional zones, may also experience greater stress from the impacts of climate change because these species may not be well-established. On the whole, sores species may be restricted bya variety of biological and physical imitations, but others will be able to adapt to the conditions brought on by climate change.

Certain wildlife species may be able to alter their diet in favor of other, exotic but newly available plant species. White-tailed deer, mule deer, moose, elk, and other species benefit from human activities that disturb ecosystems and alter habitat (22). If, for example, climate change contributes to the conversion of a dense, forested habitat to a more open area, species such as these would likely benefit. Similarly, some birds, such as robins, starlings, and @is, may adapt easily to alterations in habitat caused by climate change (22). These species tend to feed on a variety of different organisms and are territorial and aggressive in nature. They are very good at vying for resources with less competitive and smaller birds.

Migration

Some communities and ecosystems might have to migrate to survive the environmental conditions that could result from climate change. Most species of vegetation and wildlife have the ability to migrate to some extent. However, adverse conditions, such as landscape fragmentation, may limit this ability (see vol. 2,ch.5). in addition, the ability of a species to migrate depends not only on environmental conditions but on dispersal rate. Animals can generally disperse much more quickly than plants (22). However, because wildlife independent on vegetation for survival, many species are forced to migrate only as fast as vegetation does (94). Therefore, the health and survival of many species will be dependent on the response of vegetation to climate change.

Dispersal rates for vegetation are considerably slower than the projected rate of climate change,and, therefore, some species will not be able to migrate as fast as their corresponding climatic regimes. For example, most North American tree species can migrate at 12 to 25 miles (20 to 40 kilometers) per century, but climate regimes are expected to migrate at much faster rates, in some cases by at least an order of magnitude (106). In particular parts of the United States, climatic regimes may shift hundreds of miles by as early as the middle to the end of the next century (43, 74). Because some species will be unable to keep up with the pace of climate change, their range may be reduced, or they may become extinct.

Coastal and estuarine wetland vegetation will likely attempt to migrate inland as the sea level rises. Their success in migrating will depend on the steepness of the coast and obstructions to migration that might exist, such as rocky areas and human-built structures. Wetlands fringing the playa lakes of the Southwest may retreat along with the water levels if increased evaporation, in a hotter and drier climate, causes water levels to drop. Alpine tundra will likely migrate toward higher altitudes as lower areas become warmer and drier.

In all of these cases, wildlife and other organisms that are dependent on these ecosystems for survival *may* attempt to migrate as well. The least Bell's vireo, an endangered species completely dependent on riparian vegetation for survival, may lose a great deal of habitat if inland drying occurs (22). The jack-pine forest in northern Michigan, which provides critical habitat for the endangered Kirtland's warbler, could die off and be replaced by a sugar maple forest in as few as 30 years under climate change conditions (1 1).

In each case, the ability to migrate will be limited by adjacent land-use patterns and the availability of areas to which organisms can migrate. "Barriers," such as roads, cities, and agriculture, degrade habitat quality and limit the ability of vegetation and wildlife to move or spread. Roads may pose a formidable physical barrier to animal migration, and even plants may have difficulty "moving" across roads if their seeds are too heavy to be dispersed easily and overlarge distances by wind. Vast expanses of suburban developments now occupy sites that formerly could have offered either suitable destinations or pathways for migration of plants and animals from one locale to another. Many animals will not cross seemingly small obstructions, such as railroad clearings or roads, to get to nearby suitable habitat (22). Agricultural land and other highly managed areas prevent species from naturally establishing themselves. In general, the ability of plants and animals to migrate in response to climate change is largely affected by anthropocentric influences and factors. Nevertheless, many species will be sufficiently resourceful to migrate successfully, and some may even thrive and expand their ranges.

Decline and die-back

If climate change is rapid or severe, some species, ecosystems, and landscapes may not be able to adapt. Changes in climate may cause severe loss of function or value in certain species, ecosystems, and landscapes, or may result in the disappearance of certain species or entire ecosystems. Just as human land-use patterns may limit migration, they may also ultimately limit the chances for some species or ecosystems to survive. Some species are well-suited to a very narrow set of environmental conditions, but lack characteristics that would allow them to move or adapt easily to new environments. When human activities reduce or eliminate their normal habitats, these species are likely to show signs of stress leading to decline or die-back.

in forest systems, decline and die-back occur when a large proportion of a tree population exhibits visible symptoms of stress, unusual and consistent growth decreases, or death over a large area Such distinguishing characteristics can be irregular in distribution, and discontinuous but recurrent in time. In all cases, however, decline and die-back are the result of complex interactions of multiple stress factors (83). Some common abiotic factors include drought and low- and high-temperature stress. Biotic agents include defoliating insects, root-infecting fungi, and borers and bark beetles. Typically, declines are initiated by an abiotic stress, with mortality ultimately caused by a biotic stress agent.

(Cotinued on next page)

Box 2-E—Responses of Natural Systems to Climate Stress: Adaptation, Migration, and Decline--(Continued)

More often than not, the decline and die-back scenario is a direct or indirect response to a change in some climatic variable. Changes in precipitation and temperature patterns have been shown to have an interactive and sequential influence on the health of forest systems. Drought conditions tend to enhance the possibility of insect attack For example, sugar maple in northern forests is extremely sensitive to extreme changes in temperature. Moist, warm weather is particularly conducive to the spread of Eutypella canker, a serious stem disease, whereas drought periods favor the spread of *Armillaria* decay; wind damage and sudden temperature drops significantly favor certain cankerous fungi, and the lack of snow cover can result in deep root freezing (83). Nevertheless, these phenomena have sufficient common characteristics in various forest tree species to allow for some generalization; changes in climate will almost certainty exacerbate existing stresses, further influencing forest decline and die-back

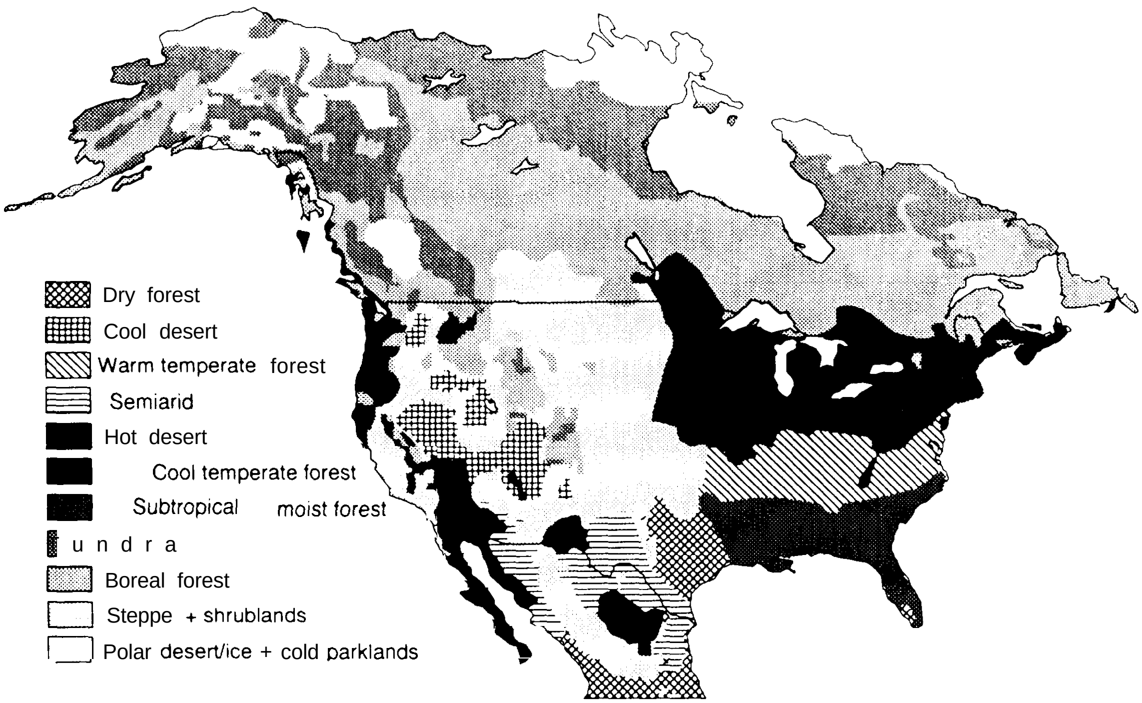
Some ecosystems will be influenced by changes in sealevel rise. For example, coastal wetlands have been able to keep pace with a sealevel rise of approximately 0.04 inches (1 mm) per year for the past 3,000 years, which Is the rate at which many marshes are able to accumulate material. However, climate change is sure to increase the rate at which sea level rises, which may ultimately drown these wetlands (98). Likewise, alpine and arctic ecosystems may shrink and, in some sites, disappear if the amount and speed of climate change exceed the rate at which these systems can migrate upslope. On the whale, the rate at which climate change occurs will have a direct effect on the rate at which ecosystems experience declines in population and die-back responses.

SOURCES: P.M. Karelva, J.G. Kingsolver, and R.B. Huey (de.), Biotic Interactions and Global Change (Sunderland, MA: Sinauer Associates, Inc., 1993), 559 pages; R.L. Peters and J.D.S. Darling, "The Greenhouse Effect and Nature Reserves," Bioscience, December 1985, pp. 707-17; C. Zabinski and M.B. Davis, "Hard Ti mes Ahead for Great Lake Forests: A Climate Threshold Model Predicts Responses to CO_2-induced Climate Change," in: The Potential Effects of Global Climate Change on The United States, Appendix D: Forests EPA-230-95-89-054, J.B. Smith and D. Tirpak (eds.) (Washington, DC: U.S. Environmental Protection Agency, June 19S9).

some areas, or for some species, slow processes of seed dispersal, soil development, and achievement of sexual maturity may curtail adaptation. Pollen records suggest **that** temperate forests can migrate at approximately 62 miles per century, but the correlated growing-season conditions may shift by 200 miles for every 4 OF (2 'C) of warming, so even in the lower range of climate change predictions, some tree species might not be able to keep up. Modeling results suggest that if a forest includes some species that are better adapted to a new climate, those species may become dominant, but if none of the species are better adapted, the whole forest might decline. However, climate change is unlikely to decimate vegetation and make land barren, except in limited areas that are now arid and that may become even drier. Rather, ecological communities are likely to change as rapidly moving and widely dispersing species (e.g., weeds) increase in number, while slower-moving species decline and disappear (21).

The adjustment process will not occur uniformly across species, communities, and ecosystems. Plants or animals attempting to migrate to new areas may face competition from those that still remain. Some migrators may be able to compete effectively, and others may not. For example, wetland vegetation may attempt to take root further inland as sea level rise inundates coastal marshes, but existing inland plants that survive may temporarily block the path. Migration may also be blocked by areas rendered unsuitable as a result of human use. Some wetland species may be more capable than others of establishing themselves among the inland vegetation. Thus, many species, as well as ecosystem processes and interactions, may be reshuffled,

Figure 2-10-The Distribution of Holdridge Life Zones Under Current Climate Conditions



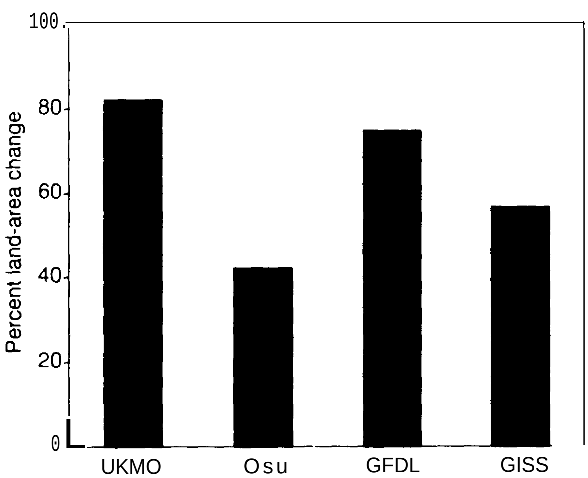
SOURCE: Office of Technology Assessment, 1993, adapted from L.R. Holdridge, *Life Zone Ecology* (San Jose, Costa Rica: Tropical Science Center, 1967), and W.R. Emanuel, H.H. Shugart, and M.P. Stevenson, "Climatic Change and the Broad Scale Distribution of Terrestrial Ecosystem Complexes," *Climatic Change*, vol. 15, 1985, pp. 75-82.

especially at the boundaries of current ecological zones, where ecosystems are the least mature and the most stressed (21). However, plants that are capable of migrating or adapting may not necessarily be the most desirable. Climate change could lead to an increase in less-valued species and a change in ecosystem composition.

Development of Asynchrony

The migration of vegetative species could put many organisms ''out of sync' with their environments and disrupt many symbiotic relationships. As plants migrate inland and upland, pollinators and other vectors that assist in the reproductive process may not *move* at the same rate. If insects and birds are left behind, plants will face significant losses in populations, and some may become extinct. This may be especially true for organisms with very specific ranges, whether they be limited by topography, precipitation, or temperature. In addition, insects and birds may arrive at their migratory destinations prematurely, before feeding and nesting conditions are optimal, or too late, after resources have been exhausted. Organisms will be exposed to different and varying conditions, such as photoperiod, intensity of sunlight, and temperature, unlike what they are currently acclimated to, which may affect reproductive capabilities as well. In addition, some plant species may alter nutrient cycles and other processes in order to adapt to new soil and moisture conditions. This could not only adversely affect the health of plants, but could reduce their nutritional value, thereby affecting the health of the wildlife that depends on them for sustenance. Marine species will face similar

Figure 2-n-Percent of U.S. Land Area Shifting Holdridge Life Zones After CO_2 Doubling



NOTE: UKMO=United Kingdom Meteorological Office, OSU=Oregon State University, GFDL=Geophysical fluid Dynamics Laboratory, and GISS=Goddard Institute for Space Studies.

SOURCE: P.N. Halpin, "Ecosystem:; at Risk to Potential Climate Change," contractor report prepared for the Office of Technology Assessment, June 1993.

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Many species of birds, like this Clark's nutcracker, are dependent on specific habitats that provide sustenance and cover. Fragmentation of these areas could have a dramatic impact on populations unable to locate mating, nesting, feeding, and over-wintering habitat.

difficulties because most fish require specific conditions for reproductive activities to occur at optimum rates. Anadromous fish (those that swim into freshwater streams from the sea to spawn) may be most affected as salinity in intertidal waterways is altered due to sea level rise. On the whole, the migration of vegetation in response to altered climate and the subsequent response of insects, birds, and other organisms could have significant impacts on ecosystem structure, function, and value.

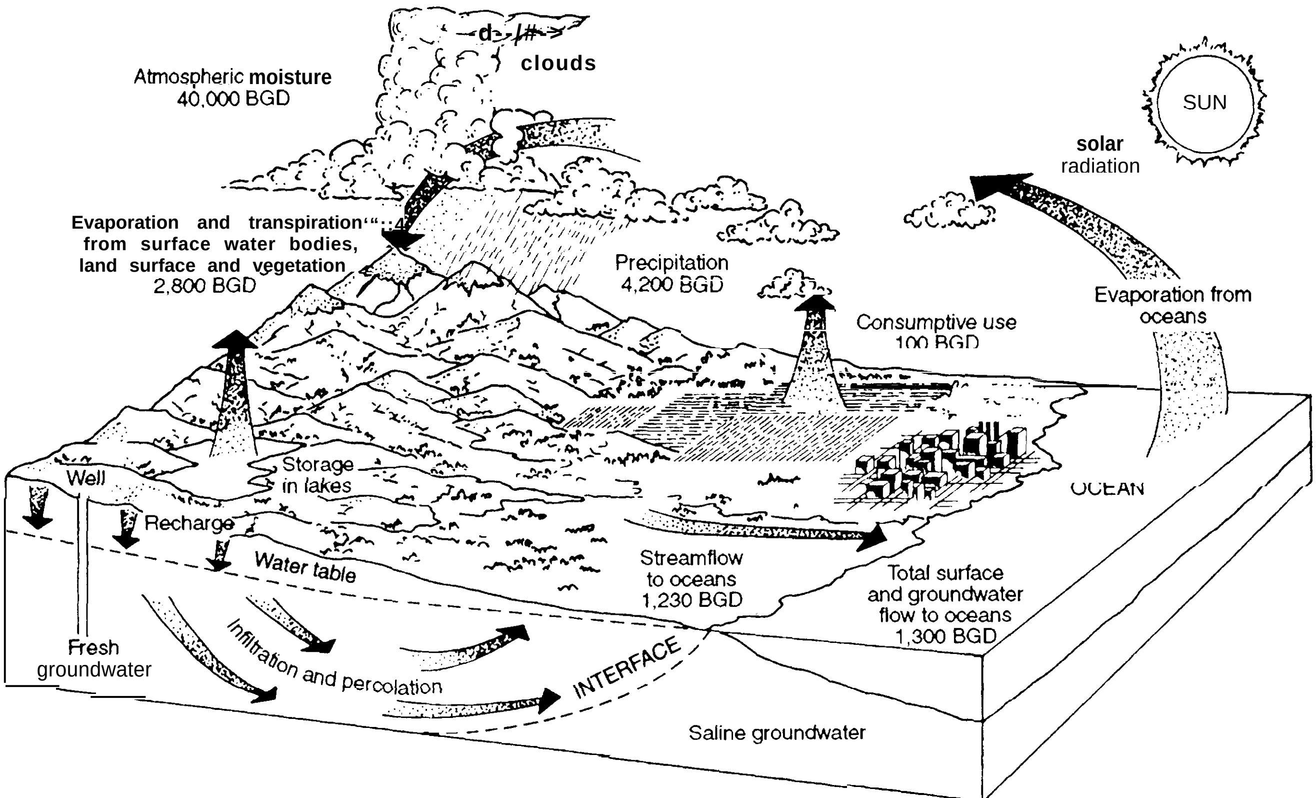
■ Interactions Among Climate, Ecosystems, and the Physical Environment

Climate change will affect living organisms both directly and indirectly, as described above, but it will also affect the processes of the physical environment in which they exist-soils and nutrient cycling, the hydrologic cycle, and photorespiration. Effects on the physical environment and living organisms will interact and cause further modifications to the environment and the organisms. Because the various biological and physical processes are intricately interconnected, with many feedbacks among them, it is difficult to predict what the overall effect of climate change will be. The following sections suggest the range of interactions between climate and the biological and physical processes it affects.

Interact/on of Water Resources and Ecosystems

Water influences ecosystem function, but ecosystems, in turn, influence the flow of water through the hydrologic cycle (see fig. 2-12 and vol. 1, ch. 5). Waterfalls to the Earth's surface in the form of precipitation. Some water stays on the surface and evaporates relatively quickly. Some percolates into the soil and is taken up by vegetation, from which it is eventually transpired through the processes of photosynthesis and respiration. The remaining precipitation moves from upland to low-lying areas--on the surface, as shallow groundwater flow toward rivers or streams, or by infiltrating more deeply into and through aquifers, eventually emptying into rivers,

Figure 2-1 2—The Hydrologic Cycle Shows How Water Moves Through the Environment



NOTE: BGD - billions of gallons per day. To convert gallons to liters, multiply by 3.785.

SOURCE: Office of Technology Assessment, 1992.

lakes, and oceans, from which it eventually evaporates-and the cycle begins again.

The extent to which water evaporates, discharges to surface water, seeps into the ground, or remains on the surface depends on the amount and form of precipitation, the temperature, the topography, the nature of soils (whether sandy or clayey, and the content of organic matter), and the types of vegetation. Vegetation moderates the cycle in several important ways: it adds to the organic matter of soils, increasing their water retention; roots and stems may physically anchor soils and slow the passage of water and channel water below ground, further reducing runoff; and canopies of leaves reduce droplet impact on the soil and affect the rate of evapotranspiration. Because of these interactions, changes in vegetation may cause changes in the hydrologic cycle. For example, a semiarid grassland that is stripped of vegetation through overgrazing (by either wild or domestic herbivores) may lose some of its ability to retain water as plants no longer slow runoff or take up water to release it slowly later. The interaction of changes in the ecosystem and the hydrological system may eventually lead to desertification.

Climate interacts with the hydrologic cycle on different scales. Global average temperatures affect how much moisture can be carried in the air, how quickly clouds form, how readily clouds yield precipitation, and how much precipitation occurs and in what form (e.g., rain or snow), as well as the large-scale wind patterns that carry clouds from one region to the next. On a regional or local scale, temperature affects the rate at which water evaporates from the surface or transpires from plants. Temperature further affects the rate of evapotranspiration by influencing the form in which precipitation falls. Rain typically runs off soon after it falls. Snow may remain on the surface for a considerable amount of time, with the delayed runoff supplying downstream and adjacent areas with water during the spring. Thus, global and regional changes in temperature and precipitation can affect the hydrologic cycle and the related ecosystem interactions in numerous ways.

The predicted changes in global climate will essentially increase the rate at which the hydrologic cycle occurs, although different hydrologic models yield rather different scenarios of what the regional results will be (79). As outlined above and in volume 1, chapter 5, total global precipitation is expected to increase 7 to 15 percent, but warmer temperatures will allow for greater and more rapid evapotranspiration, which could lead to drier conditions in some areas (particularly in midcontinent, midlatitude regions). Hydrologic studies suggest that river watersheds can be quite sensitive to even small climatic changes, particularly in arid and semiarid areas, where annual runoff tends to be highly variable. In river basins where snowmelt is important, both the annual total runoff and its seasonal distribution can be affected by changes in temperature and precipitation. Overall, climate change is expected to lead to significant changes in both high-flow and low-flow runoff extremes (42).

Soils, Nutrients, and Vegetation

Soil development and nutrient cycling rely on a dynamic interaction among rock, plants, fungi and microorganisms, and atmosphere. The development of soils depends in part on the rock that contributes sediments as it erodes and weathers, on the kinds of plants that grow on the soil generating detritus of varying composition, and on the microorganisms associated with the plants that decompose the detritus into nutrients and organic matter. Nutrients, including carbon and nitrogen, are cycled in various forms through plants, soil, and the atmosphere. The type of soil that has developed may limit the kinds of plants that can easily take root and survive (which then provide habitat for particular animal species that affect nutrient turnover from plants). The presence of vegetation further affects the soil by anchoring it, thus preventing erosion.

Both temperature and moisture affect the type of vegetation that grows, the amount of detritus produced, and the rate at which litter decomposes and releases nutrients that can then be used by other plants, animals, and microorganisms. With intermediate levels of moisture, increased temperatures accelerate decomposition. This may free more nutrients in the short term, potentially boosting productivity. However, faster decomposition could also release more carbon (in the form of CO_2 from the soil, particularly in the northern United States, where soils store a large share of the global carbon, thus amplifying the greenhouse effect. Furthermore, as described in the earlier section on CO_2, increased concentrations of atmospheric CO_2 will likely lead to changes in the composition and structure of plant leaves. The ratio of carbon to nitrogen may increase, which may actually slow the rate at which these leaves decompose and release minerals (see box 2-D). Changes in precipitation and runoff will also affect whether nutrients are maintained or lost more quickly from soils. More-frequent or more-severe storms could cause more erosion and soil loss in areas where land use is intensive or where vegetation has declined because of altered climate conditions (19, 42, 64).

The overall effects of climate change on soils are difficult to calculate because of the many complex and interacting processes that contribute to soil development. Regardless of the long-term change in soils, in the shorter term, soils may play an important role in vegetation changes. As temperatures warm, the suitable ranges or climate conditions for many plant species may expand northward. However, soils at the northern edge of the United States and into central Canada tend to be thinner and less fertile than those in the

Midwest, which may make adaptation difficult for some species. In agricultural systems, any lack of nutrients in the soils can be compensated for by adding fertilizers, although there may be environmental costs associated with this (see vol. 1, ch. 6).

Sea Level, Oceans, and Coastal Ecosystems

The many interconnected physical changes in oceans and coasts will affect marine ecosystems in numerous ways (see box 2-C). Wave patterns in certain areas could be altered as a result of changes in regional climate, which could affect the stability of coastal areas.

Coral-building organisms thrive at a rather narrow range of water temperatures and depths. Although these organisms build reefs at a rate of up to 0.6 inches (1.5 cm) per year, fast enough to keep up with predicted sea level rise, other factors such as storms and warmer water temperatures could interfere with their growth and, in some cases, could kill the organisms. Loss of coral reefs would change the wave and water patterns near the coast and could allow for increased coastal erosion. Likewise, mangrove trees along many tropical coasts play an important role in shore stabilization. Sea level rise could inundate some mangrove swamps. As these trees die, the coast would be left vulnerable to erosion. In addition, the potential elimination of salt marshes and seagrass beds could have serious effects on marine organisms. However, wetlands may migrate landward at a rate dictated by the landward slope and sea level rise. In any case, the physical and biological changes along oceans and coasts could interact to amplify the effects of climate change (see vol. 1, ch. 4).

WHICH NATURAL RESOURCES ARE MOST VULNERABLE TO CLIMATE CHANGE?

Although regional predictions of the natural resources most at risk from climate change cannot be made based on existing knowledge, certain characteristics may put some parts of a natural resource system at greater risk than others. For example, ecosystems with limited options for adaptability-such as alpine ecosystems, old-growth forests, fragmented habitats, and areas already under stress-may be particularly vulnerable to changes in climate (42) (see vol. 2, ch, 5). How ecosystems will fare under climate change also depends on other factors that influence soil and water chemistry, including land use, air pollution, and water use (21). Although systems at the edges of their ranges and those already stressed may be at the greatest risk from climate change, some systems that now appear healthy could also suffer.

Natural ecosystems may be more vulnerable to climate change than managed ones. Furthermore, natural or less managed ecosystems may be affected not only by changes in climate, but by further stresses resulting from human responses to those changes, such as increased irrigation, diversion of water from streams, and expanded tillage or grazing (see vol. 2, chs. 4 and 5). On the other hand, poor management responses in forestry and agriculture, such as planting species that are not well-adapted or maintainingg stands at high densities, could make some managed areas vulnerable as well (see vol. 1, ch. 6, and vol. 2, ch. 6). Vulnerability to climate change will certainly vary widely, and predictions about how systems will respond to climate change are difficult to make.

Changes in soil moisture may be among the best indicators that a natural resource system is becoming stressed. Figures 2-6 and 2-7 illustrate areas of the United States that may face changes in soil moisture under the climate change scenarios projected by GCMS. The extent to which these changes in soil moisture will affect areas of significant natural cover (34) is presented in figure 2-13. The figure shows the percent of area in each land class that is becoming effectively wetter (measured above the zero axis) or drier (below the zero axis). The GFDL scenario produces dramatic effects, with the majority of all existing ecosystems except tundra and deserts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Natural disturbances, such as the Yellowstone fires, create openings in forested areas where grasses and wildflowers can flourish. This provides new food sources for elk and other wildlife. Fires also promote recycling of nutrients, which enriches the soil,

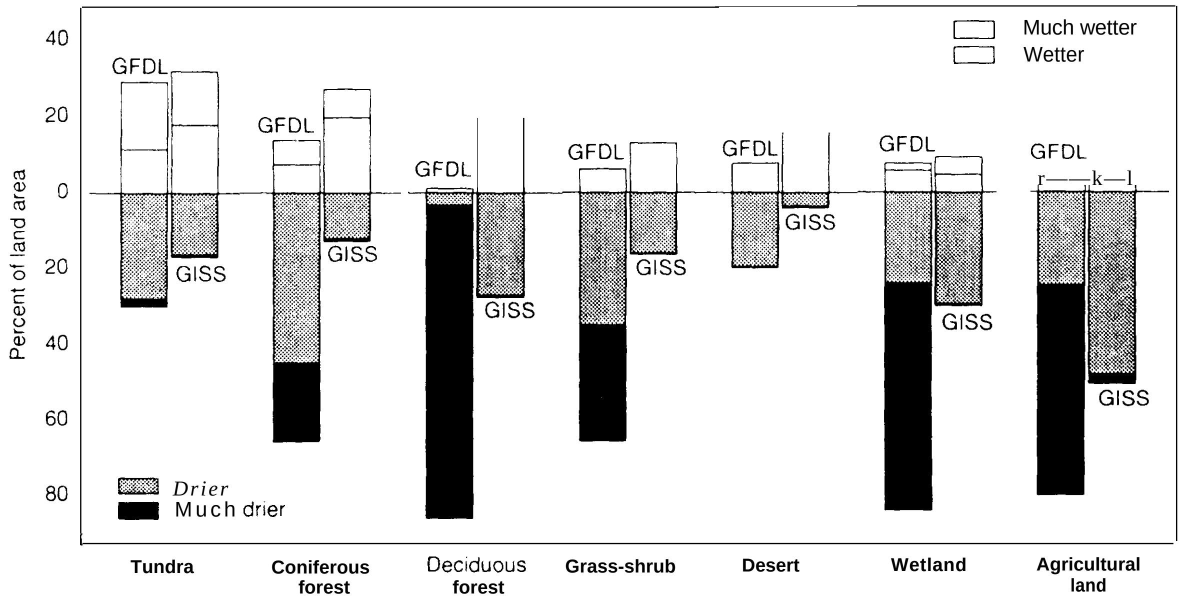
moving toward drier climatic regimes. Almost 80 percent of agricultural lands of the United States face drying under the GFDL scenario. The GISS scenario produces a mix of wetting and drying in areas of natural cover, with the exception of some noticeable drying in the wetlands. Agricultural lands (the Midwestern corn belt and California) are more effected, with over 40 percent of the agricultural lands showing some drying under the GISS scenario.

Natural resource systems could change in any number of ways in response to a changing climate, but not all changes damage things that humans value. For example, a gradual shift in the boundaries of a wetland would probably not be considered a damage unless this results in a reduction of the habitat, flood control, water faltering, or recreational services offered by that wetland. Similarly, an increase in tree mortality may be of no concern in a forest valued as wildlife habitat rather than as a source of timber supply.

The degree of human intervention may also influence the vulnerability of natural resource systems to climate change. Depending on how natural systems are valued, they may be managed along a spectrum from active to passive management regimes. Because intensively managed systems are considered valuable, and because people are already exerting effort and expense to keep them productive, use of additional measures to respond to a changing climate is likely. On the other hand, wilderness areas are essentially unmanaged-but highly valued precisely because of this lack of management. Active intervention to protect these areas seems unlikely (see vol. 2, ch. 5), but there may be little loss of value from any but the most extreme effects of climate change on these natural areas. Thus, climate impacts on natural resource systems and the need for taking precautionary actions in preparation for climate changes cannot be evaluated without also considering how people value and manage these resources. These are the issues considered in subsequent chapters that investigate the effects of and possible responses to climate change in individual natural resource sectors: coastal systems, water resources, agriculture, wetlands, preserves, and forests.

The Intergovernmental Panel on Climate Change, the National Academy of Sciences, and the U.S. Environmental Protection Agency have all conducted assessments of the potential impacts of climate change (see box 2-F). Their reviews describe numerous impacts of climate change on U.S. natural resource systems, which laid the foundation for this report. Subsequent chapters will summmize some of the predictions made by these reports for individual natural resources, then explore in greater detail the

Figure 2-13-Soil-Moisture Changes Under the GFDL and GISS Climate Change Scenarios, by Land-Use and Cover Type



NOTE: Bars above the zero axis represent the percent of land-use area predicted to become wetter; bars below the axis show the percent of land area becoming drier. Drying or wetting is calculated from the change in the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET), No change is reported if the index changed (up or down) by leas than 0.025; wetter= 0.25 to 0.05; much wetter= >0.05; drier= -0.25 to -0.05; much drier. <-0.05. GFDL=Geophysical Fluid Dynamics Laboratory, GISS=Goddard Institute for Space Studies.

SOURCE: P.N. Halpin, "Ecosystems at Risk to Potential Climate Change," contractor report prepared forthe Office of Technology Assessment, June 1993.

vulnerability and adaptability of the various resources and the potential management strategies and policies that might assist adaptation.

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Box 2-F--Major Assessments of Climate Change Impacts

Three major assessments by national and international organizations have addressed the potential impacts of climate change: the U.S. Environmental Protection Agency's (EPA's) 1989 report, The Potential Effects of Climate Change (94), the three-volume climate change series issued by the Intergovernmental Panel on Climate Change in 1990 (42, 43,44, and the 1992 supplement (45)), and a 1991 report by the National **Academy of Sciences,** *Policy Implications of Greenhouse Warming (22),* and its 1992 supplement These reports focus on different aspects of climate change. Taken together, they lay the foundations for OTA's assessment of the adaptability and vulnerabilityof systems to climate change, and their findings are cited throughout this chapter![1]

The EPA Report-In 1987, Congress requested that EPA study "the potentialhealth and environmental effects of climate change including, but not... limited to, the potential impacts on agriculture, forests, wetlands, human health, rivers, lakes, estuaries, as well as societal impacts.'' To respond, EPA conducted a massive 2-year effort, hiring more than a hundred contractors to model potential effects on each system, and contracting out several regional case studies to integrate how all impacts might interact in different regions. The results **were** synthesized in a 400-page report accompanied by 11 appendixes of contractor papers.

EPA used regional predictions of temperature and precipitation generated by four major general circulation models (GCMs) to examine the sensitivities of managed and unmanaged systems and to evaluate regional effects. The climate predictions were distributed to contractors, who then incorporated the results into their own models for crop growth, forest productivity, farm-level decisionmaking, etc., to predict the potential effects on particular systems and in particular regions.

EPA found that unmanaged systems such as coastal wetlands, parks, and forests "may be unable to adapt quickly to rapid warming." Effects could include a reduced range for many tree species, changes in forest composition, a decline in cold-water fish and shellfish (although some warm-water species could benefit), an increase in species extinction, loss of coastal wetlands, and an increase in salinization of estuaries. Such impacts could begin in 30 to 80 years. Climate changes may heighten the effects of other stresses (such as pollution, increased radiation accompanying stratospheric ozone depletion, pests and pathogens, and fire). For example, climate-induced stress may make large regions of forests more susceptible to other stresses, such as fire, pests, disease outbreaks, wind damage, and air pollution. Changes in forest species and productivity could lead to secondary effects such as increased soil runoff and erosion, reduced aquifer recharge, reduced biodiversity, and changes in wildlife habitat and recreational opportunities. Species extinctions could increase (and biological diversity could decline), especially in areas where roads, agriculture, and urban development block or restrict migration pathways or habitat, and in areas that harbor heat-or drought-sensitive species. Some forested land could become grassland. As communities and ecosystems are displaced by climate change, it may be necessary to expand scientific knowledge on the practice of ecosystem restoration, so that Communities can be rebuilt in degraded sites or relocated to new areas where they have not existed in the past (94) (see also vol. 2, boxes 4-A and 5-M).

Overall, EPA found that managed systems such as water resources and agriculture are more capable than natural systems of withstanding climate change. However, problems may still arise as humans attempt to adapt to the changes to these systems brought about by climate **change.** Agricultural yields might be reduced, but productivity could shift northward so that overall production could probably meet domestic needs, with some possible reductions in exports. Farmers might have to change their practices, such as beginning or increasing irrigation, which might increase conflicts over water use. If climate change leads to reduced stream flows, water quality may suffer because less water will be available for diluting or flushing pollutants and dissipating heat;these

1 All three reports were based on the assumption that there would be no major changes in climate variability.

changes could affect fish and wildlife populations. The effects on agriculture might vary considerably over regions, with declines, for example, in crop acreage in the Great Plains potentially offset by increased acreage in the Great Lakes States.

Quality of life may not suffer much in areas where, for example, forests shift from one species to another, and where the shifts are gradual; however, in areas where forests die out altogether (such as may occur in some parts of California), people would face severe environmental and land-use effects. Recreation relies on relatively healthy forests;rapid changes that caused stressed or declining forests would likely reduce recreational opportunities and demand.

The IPCC Report--The intergovernmental Panel on Climate Change (IPCC) is an international group of hundreds of scientists from more than 50 countries established in 1988 by the World Meteorological Organization and the United Nations Environment Program. The IPCC setup three working groups: Working Group i to assess the scientific basis for how human activities affect the climate; Working Group ii to study the potential impacts of climate change worldwide; and Working Group III to formulate possible policy responses. The results were published in the three-volume *Climate Change* report in 1990 (The IPCC Scientific Assessment, The IPCC Impacts Assessment, and The IPCC Response Strategies). The working groups continue to meet, and issue occasional updates to the 1990 reports.

The scientific assessment predicted that under a "business-as-usual" scenario (characterized by continued reliance on coal-intensive energy sources and only modest efficiency increases), the global average temperature would increase at a rate of 0.5‘F (0.3%) per decade, with a likely increase of 2 °F (1 °C) over current levels by 2025 and 5.4 °F (3 °C) before the end of the next century. The impact assessment used this business-as-usual prediction for increasing temperature (with accompanying estimates that equivalent atmospheric $C0_2$ concentrations[2] would double by 2025 to 2050 and sea level would rise about 1 foot (0.3 meter) by 2030) to predict potential impacts on systems including natural terrestrial ecosystems, agriculture, and forestry.

IPCC suggested that climate change could shift climatic zones several hundred miles toward the poles over the next 50 years, requiring natural terrestrial ecosystems to either migrate or adapt to a new climate regime. The rate of change will determine the degree of impacts: some species might be able to keep up with change, but some could become extinct, thus reducing global biodiversity. Ecosystems are unlikely to move as units, but will develop new structures as species abundance and distribution are altered. Most at risk are systems with limited options for adaptability (montane, alpine, and polar areas, island and coastal communities, remnant vegetation, heritage sites or reserves, and areas already under stress). Sealevel rise and ocean warming will affect fisheries, potentially reducing habitat for several commercially important species. Coastal wetlands maybe inundated by rising seas and forced to migrate inward, though in many areas, this may not be possible. inland wetland areas may come under increased pressure for agricultural use. As for managed systems, forests may become more susceptible to parasites, and losses from fires will increase. It is unclear whether global agricultural productivity would increase or decrease overall, but many regions are likely to experience shifts or losses in production (for example, a decline in cereal and horticultural production in the southern United States), which will alter trade patterns. Impacts will differ considerably from region to region, as will the socioeconomic effects. Water availability will likely increase in some areas and decrease in others, but regional details are not yet known. There may also be a change in drought risk, which could seriously affect agriculture at both the regional and global levels.

The NAS Report-The National Academy of Sciences (NAS) convened three different scientific panels to conduct preliminary analyses of climate change effects, mitigation strategies, and adaptation strategies. Each panel drafted a report that described their analyses and conclusions. A fourth “synthesis” panel drew on the work of the other three panels to formulate a policy report, which was published in April 1991.

2 The cumulative warming effect of all greenhouse gases is equivalent to a doubled $C0_2$ concentration.

(Continued on next page)

Box 2-F-Major Assessments of Climate Change Impacts--(Continued)

The NAS panels assumed greenhouse warming in the range of 2 to 9°F (1 to 5°C), but did not give a specific time frame of reference. Based on this scenario, NAS classified natural resource systems and human activities into one of three categories: low sensitivity to climate change within the given range; sensitive but adaptable at a cost; and sensitive with questionable ability to adjust or adapt. NAS concluded that built systems generally fit into the first or second categories, and managed crop or timber lands fit into the second.

Water resources are quite sensitive to climate because runoff is the "small difference between the larger quantities of precipitation and evaporation," and runoff "fluctuates relatively more" than either precipitation or evaporation. Changes in runoff will have adverse impacts only when water supply no longer matches water demand for use and consumption. In the United States, water supply and demand are now closely matched in the Great Basin, Missouri, and California water regions, so these areas maybe particularly vulnerable to decreases in precipitation (and conversely, they would reap large benefits should precipitation increase). Activities such as irrigation are also vulnerable to decreased precipitation because irrigation is most common in areas where precipitation is already light and evaporation is high. Unless climate changes quickly relative to demographic changes that affect water demand, however, the NAS report concludes, "the overall impact of climate change is unlikely to be substantially more serious than that of the vagaries of the current climate" (21).

In contrast, NAS suggested that unmanaged ecosystems--the "natural landscape" and marine ecosystems--respond relatively slowly to climate change and that their ability to adapt is questionable and "problematic."

SOURCE: Office of Technologyy Assessment, 1993.

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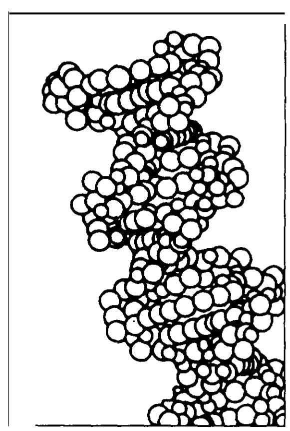
Global Change Research in the Federal Government 3

On October 13, 1992, the United States ratified the United Nations Framework Convention on Climate Change. The convention was one of the key accomplishments of the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. Its declared goal is ‘‘stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system, ’ and it calls for parties to return “individually or jointly to their 1990 levels of these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol” (46). Most of the 166 countries that signed the convention have pledged to do so by 2000 (on April 21, 1993, President Clinton made a commitment to reduce U.S. greenhouse gas emissions to 1990 levels by that year). The convention also requires all participating countries to prepare action plans detailing their strategy to mitigate climate change. The Biodiversity Convention, signed by most developing and industrialized countries at UNCED, calls for the development of strategies for global biodiversity conservation, and Agenda 21, the comprehensive action agenda to promote sustainable development adopted at UNCED, also calls for policies to minimize environmental degradation.

All these concerns about climate change, biodiversity, and sustainable development reflect a policy agenda that is inextricably linked to scientific research. “The relationships between scientific and technological advancement and government support are complex, and the stakes in these decisions are high, not just for scientists and engineers, but for society as a whole. Consequently, a better understanding of the process of articulating goals, both within and outside science, is vital” (3).



The Federal Government launched a multiagency research effort in 1989 in response to the uncertainties and potential risks of climate change. Its purpose is to observe, understand, and predict global change (9) When the U.S. Global Change Research Program (USGCRP) was created as a Presidential Initiative in 1989, it did not have an explicit plan to link research to policy. Before codifying the program, Congress directed it to provide information useful to policy makers; however, Congress did not identify or mandate any mechanism to ensure this. When the program was first implemented, key questions of the scientists and policy makers were: Are humans significantly changing the climate, and can climate change be predicted? The program was intended to replace a crisis-driven, one-problem-at-a-time approach to environmental problems with a more systemic, proactive approach that recognizes that different environmental problems are linked by the very nature of the Earth system.[1] Although the program is scientifically well--grounded, it has become overwhelmingly a physical science program focused on basic Earth system processes that largely ignores the behavioral, economic, and ecological aspects of environmental problems. For example, understanding the role clouds play in climate change and the role of the ocean-kind-atmosphere interface is now its highest priority.

Understanding the size and scope of USGCRP can be difficult, and the coordination challenges of such a large interagency program are formidable. Agency personnel committed to the program have made a commendable effort to ensure that the program functions smoothly. However, USGCRP is not a managed entity with one budget, nor does it have an authoritative body making decisions on projects. It is, rather, a loosely coordinated collection of several programs and budgets. Even this level of coordination is undermined at the legislative level, where the program, collected into a compilation of budgets by the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), is splintered into several parts and never considered as a whole during the authorization, appropriation, and oversight processes.

The primary questions of policy makers have changed since 1989 in the wake of the world climate treaty and the publication of several key reports: the Intergovernmental Panel on Climate Change (IPCC) reports, the Environmental Protection Agency (EPA) reports on the potential effects of climate change and policy options, and the Committee on Science, Engineering and Public Policy (COSEPUP) report.[2] It is now generally accepted that unequivocal detection of the greenhouse effect requires another decade of measurements, and that rates of climate change and regional details about climate changes will not be available for at least that long (see ch. 2). Thus, questions being asked today have moved beyond the basic science issues of "observing, understanding and predicting' climate change to a second set of concerns: What can be done to mitigate or adapt to climate change? What are the climate effects of most concern? How can we manage natural and human systems wisely given an uncertain climate? Consequently, USGCRP'S mission statement and priorities are now too narrow to address questions such as how to minimum negative impacts of climate change.

The congressional committees requesting this study recognized that decisionmaking must continue in the face of uncertainty. They expressed the following concerns to the Office of Technology Assessment (OTA):

[1] The *Earth* system is the sum of all interactions among living organisms and their biotic and abiotic environments.

[2] IPCC's *Scientific Assessment (28), Impacts Assessment (26), Response Strategies (27),* and *Supplementary Report to the IPCC Scientific Assessment* (29); EPA's *Policy Options for Stabilizing Global Climate* (52) and *The Potential Effects of Global Climate Change on the United States (51);* and COSEPUP's Panel on Policy Implications of Greenhouse Warming, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base (10).*

- "We think it is prudent to begin--today—investigating how our research and development programs should incorporate concerns about climatic uncertainty. "[3]
- ''Do current U.S. R&D Programs focus on the right questions to provide information about effects on different systems, potential strategies for making systems more resilient in the face of climate change and adapting to such changes that may occur?'
- "What information can more research provide over various time frames to guide decisions about reducing greenhouse gas emissions, ameliorating effects of global climate change, and building resiliency into systems?'

Conducting research to answer some of these questions has been a low priority. Although the results of the program, as currently structured, will provide valuable information for predicting climate change, they will not necessarily contribute to the information needed by public and private decisionmakers to respond to global change. Three areas are particularly lacking: ecosystem-scale research, adaptation research (ecological, human, and economic), and integrated assessments (evaluation of all focused and contributing research results and their implication for public policy). Research can begin now on topics more closely related to policy decisions despite incomplete answers from the physical sciences. More research is needed on the impacts of climate change on natural and managed ecosystems and the resulting implications for land and water resource management, on how people adapt, and on why people resist change. Key projects for a USGCRP committed to policy-relevant research should also include gathering information about the relative importance of population size and expectations of quality-of-life improvements, the demand for goods and services (including clean water, agriculture and forestry products, and access to natural areas), and economic and institutional barrriers to the dissemination and adoption of technological innovation. Some of the research in these areas will take decades and, if started now, may leave us much better prepared to respond to global change in the future.

Implicit in the current structure of USGCRP is that the initiation of a comprehensive adaptation research program must wait until predictions of climate change are reliable. However, there are several important reasons not to wait to initiate adaptation research. First, according to IPCC estimates, few reliable predictions of climate change on a regional scale will be available before the next 15 to 20 years. Although such regional information might help focus research on managed and natural systems in areas expected to experience the most change, research on ecosystems is a multidecade task (see vol. 2, chs. 4-6) and should begin now. Second, even though the effects of climate change on a regional level cannot currently be modeled accurately, general effects can be predicted, such as sea level rise. Adaptation research that addresses sea level rise and other effects of climate change need not wait for reliable predictions. Third, much adaptation research makes sense regardless of climate change. For example, restoration of wetlands addresses adaptation to climate change, but it also addresses the current depletion of wetlands due to other causes. Adaptation research can use historical records of societal, economic, and environmental impacts of environmental change combined with reasonable hypothetical scenarios for future environmental change (31).

Because policy makers and scientists have different educational and professiona1 backgrounds, scientific research findings need to be translated

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[3] House Committee on Science, Space, and Technology, letter to OTA, Sept. 27, 1991.

[4] Senate Committee on Environment and Public Works, letter to OTA, Oct. 4, 1991,

[5] Senate Committee on Commerce, Science, and Transportation, letter to OTA, Oct. 8, 1991,

into terms relevant to policy making and decisionmaking. Regardless of the "completeness" of climate research, policy makers are making decisions now that affect global change and whether the Nation will mitigate and/or adapt to it. They also decide where to allocate scarce resources for research.

A recent National Research Council report, *Research to Protect, Restore, and Manage the Environment (37),* stated: "No matter how good the science, environmental problems cannot be solved without integrating the science with environmental policy. To accomplish that, integrative study is needed to bridge the multidisciplinary gaps and deal with the conflicting goals held by varied constituencies. Research is necessary but not sufficient to solve problems. ' One way to improve the relevance of research results for policy makers is through the use of integrated assessments. Integrated assessments are a mechanism for synthesizing all the research relevant to an identified problem and for presenting research results in policy-relevant language. Such assessments, if conducted by multidisciplinary teams on a regular basis, could help bring together and evaluate research results produced by USGCRP, which is now composed largely of isolated programs and projects.

Although assessments were not included in the original USGCRP program, they are included in a rudimentary form in the FY 1994 budget (8). However, there has been no fundamental change in the mission of USGCRP, which remains predominately focused on understanding climate change. As a result, different people draw different conclusions about what changes in research focus to expect from USGCRP. In addition, the quality of assessments is determined solely by the information fed into them and the backgrounds of those constructing the assessment framework. If ecological, economic, and sociological research continues to be neglected, the planned assessments will not be useful to policy makers (24). John Gibbons, assistant to the President for science and technology, testified recently that USGCRP needs to expand the scope of its research to include the impacts of climate change on natural and human environments and strategies for mitigating and adapting to climate change. He also recognized the need to improve the integration of research with policy making (20).

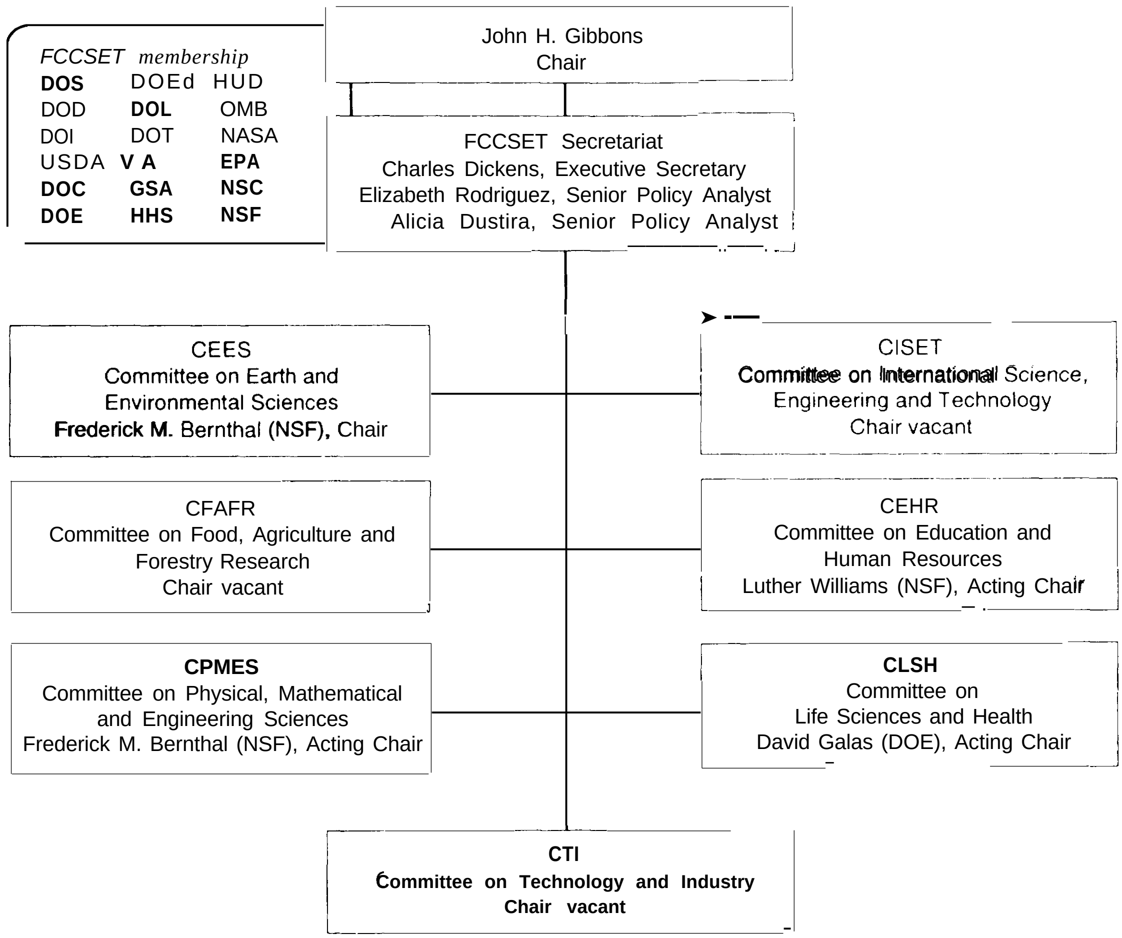
This chapter will examine the broad issues surrounding the Federal research effort to understand climate change-particularly within the context of the natural and managed systems discussed in chapters 4 through 6 of volumes 1 and 2. The options presented here, if implemented, could help commit the Federal Government to addressing areas of imbalance in USGCRP, the need for adaptation research, and the issues surrounding a national research program with an explicit science-policy interface. These program changes could benefit policy makers and decisionmakers by ensuring that USGCRP and other federally funded global change research supply the integrated information they need to make choices in the face of uncertainty about global change and its impacts.

THE U.S. GLOBAL CHANGE RESEARCH PROGRAM

Inception and Structure

Recognition that human activity could significantly alter the global environment grew during the 1970s and 1980s. Concerns focused particularly on the threat of climate change from increased emissions of greenhouse gases and the depletion of the ozone layer by chlorofluorocarbons (CFCS). In response to the potential risks of climate change and the uncertainties surrounding the science, the Federal Government launched a massive, multiagency research effort in 1989 "to observe, understand, and, ultimately, predict global changes and to determine the mechanisms influencing these changes" (9). In 1989, USGCRP was developed by the Committee on Earth Sciences (now the Committee on Earth and

Figure 3-l A-Organizational Chart for the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET)



NOTE: For definition of terms, see figure 3-1 B, next page.

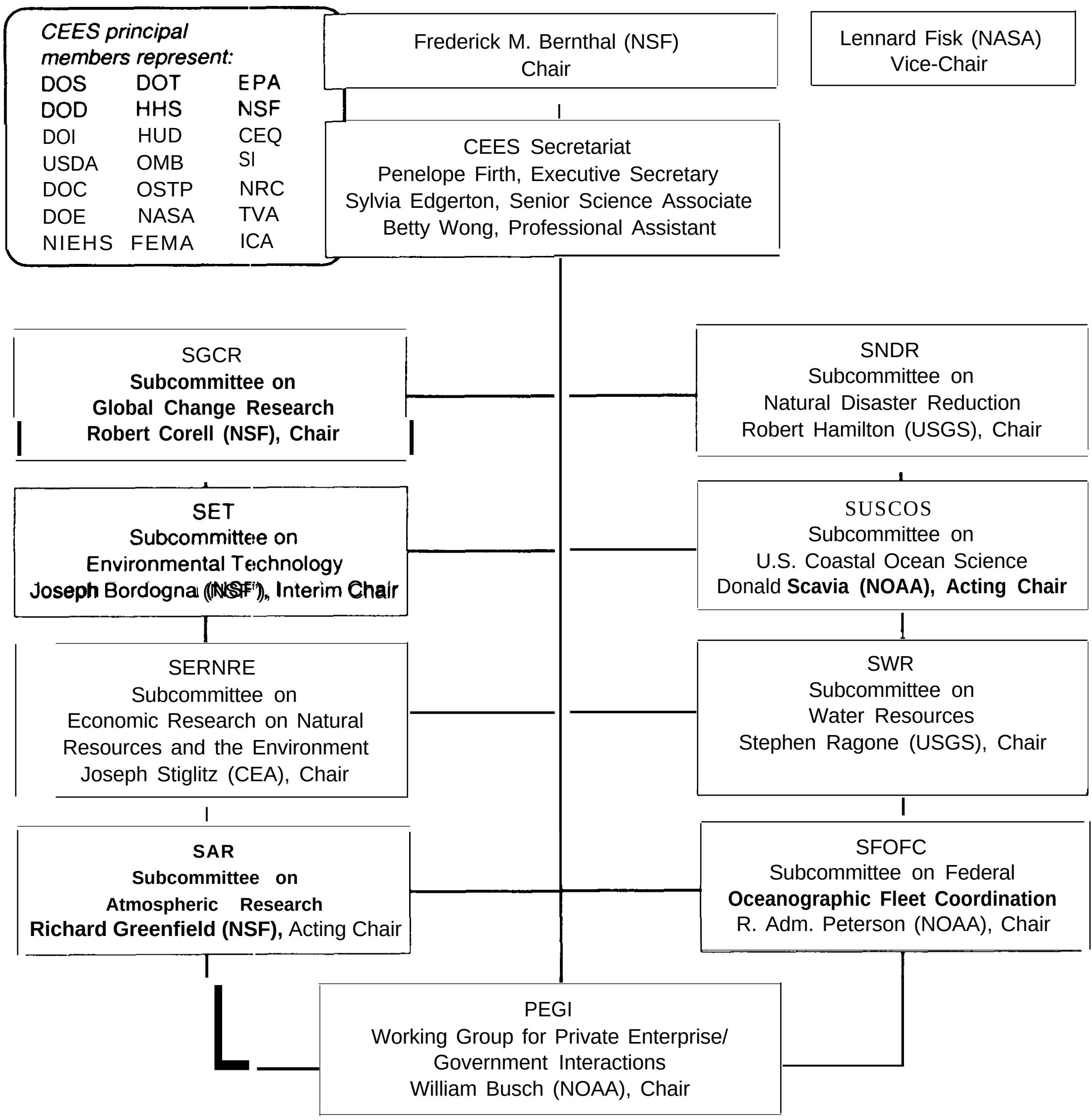
(Continued)

Environmental Sciences, CEES), an interagency group under FCCSET in the President's Office of Science and Technology Policy (OSTP) (see fig. 3-l). USGCRP became the first Presidential Initiative[6] indicating that it was to be a high-priority program with strong administrative backing. In 1990, Congress passed the U.S. Global Change Research Act (P.L. 101-606), which codified USGCRP. In 1992, USGCRP became a National Research Program.[7] Between FY 1989 and FY 1993, the Government spent $3.7 billion on this effort. A new administration that asserts its commitment to taking action on climate change issues and a Congress with a large number of new members coincide with this 5-year benchmark and could change the direction and scope of the

6 Presidential Initiatives are programs of particular importance to the national interest. Aside from USGCRP, four other Presidential Initiatives exist: high-performance computing and communication, advanced materials and processing, biotechnology research, and mathematics and science education. The Administration uses FCCSET to coordinate interagency research in these areas.

7 FCCSET developed this category for continuing Presidential Initiatives that have reached maturity.

Figure 3-1 B-Organizational Chart for the Committee on Earth and Environmental Sciences (CEES)



NOTE: DOS=Department of State; DOD=Department of Defense; DOI=Department of the Interior; USDA=U.S. Department of Agriculture; DOC=Department of Commerce; DOE=Department of Energy; DOEd=Department of Education; DOL=Department of Labor; DOT=Department of Transportation; VA= Department of Veterans Affairs; GSA=General Services Administration; HHS=Department of Health and Human Services; HUD=Department of Housing and Urban Development; OMB=Office of Management and Budget; NASA=National Aeronautics and Space Administration; EPA=Environmental Protection Agency; NSC=National Security Council; NSF=National Science Foundation; NIEHS=National Institute of Environmental and Health Sciences; OSTP=Office of Science Technology Policy; FEMA=Federal Emergency Management Agency; CEQ=Council on Environmental Quality; SI=Smithsonian Institution; NRC=National Research Council; TVA=Tennessee Valley Authority; ICA=Intelligence Community Affairs; CEA=Council of Economic Advisors; USGS=U.S. Geological Survey; NOAA=National Oceanic and Atmospheric Administration.

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1994 U.S. Global Change Research Program* (Washington, DC: CEES, 1993).

program for FY 1994. There is no official termination date for the program; however, program plans indicate that it will last at least 40 years (11).

Three "activity streams," or program elements, defined the USGCRP mission between its inception and FY 1994:

- Documentation and analysis of Earth system changes, which include observation—using both ground- and space-based observation systems—and data management;
- Process Research to enhance the understanding of the physical, geological, chemical, biological, and social processes that influence Earth system behavior; and
- Integrated Modeling and Prediction of Earth system processes.

Each of these priorities is represented by a working group under the Subcommittee on Global Change Research under CEES. The chair of the subcommittee along with the chair of each of the working groups make up the principal body responsible for the planning, development, coordination, and review of USGCRP (7). In FY 1994, a new activity stream, Assessment, was added.

USGCRP was originally envisioned as a complete *global change* research program, covering research on natural climate change, human-induced climate change, impacts of climate and land-use change on the Earth system, and impacts of human activity on ecosystem health. The program has evolved in parallel with the Intergovernmental Panel on Climate Change (IPCC) and has drawn heavily from the panel's work.[8] Consequently, the main focus of **global change** research under USGCRP has become climate change. Important global changes other than human-induced climate change, such as loss of biodiversity, changes in land use, and increases in industrial pollution, were determined to be beyond the scope of USGCRP and are addressed only to the extent that they interact with the climate system. This is reflected in the research priorities of the program's science elements.

To guide research, CEES identified and prioritized seven scientific research elements, or science elements.[9] In order of priority, the science elements are Climate and Hydrologic Systems, Biogeochemical Dynamics, Ecological Systems and Dynamics, Earth System History, Human Interactions, Solid Earth Processes, and Solar Influences (7). More-specific areas of research are prioritized under each of these seven research elements (see fig. 3-2). Several criteria, although not applied systematically, are used to evaluate projects under each research element, including: relevance and contribution to the overall goal of the program, scientific merit, ease or readiness of implementation, links to other agencies and international partners, cost, and agency approval.

New Developments

In 1992, CEES began developing a management plan for the program that would include the addition of Assessment as a fourth activity stream along with Documentation, Process Research, and Integrated Modeling and Prediction (see fig. 3-3). The primary function of the Assessment working group is to ''. . document the state of scientific knowledge and address the implications of the science of global change for national and international policy-making activities over abroad spectrum of global and regional environmental issues" (8). The group will also help coordinate the scientific assessments of global change with

[8] IPCC is an intergovernmental body sponsored jointly by the World Meteorological Organization and the United Nation's Environmental Programme. The group was set up in 1988 to assess the scientific undemanding of natural and human-induced climate change, its impacts, and potential response strategies. IPCC is scheduled to produce another full assessment in 1995,

[9] CEES (formerly CES) works closely with and has drawn heavily on the ongoing activities of the National Academy of Sciences (NAS), the World Climate Research Program (WCRP) of the World Meteorological Organization, the International Council of Scientific Unions (ICSU), the International Geosphere-Biosphere Program (IGBP), and IPCC in designing the structure of USGCRP and in identifying the program's key scientific issues and research priorities.

Figure 3-2—Priority Framework for USGCRP

STRATEGIC PRIORITIES

- Support broad U.S. and international scientific effort
- Identify natural and human-induced changes
- Focus on interactions and interdisciplinary science
- Share financial burden, use the best resources, and encourage full participation

INTEGRATING PRIORITIES

- Documentation of Earth system change
  - Observational programs
  - Data-management systems
- Focused studies on controlling processes and improved understanding
- Integrated conceptual and predictive models

SCIENCE PRIORITIES

Climate and hydrologic systems	Biogeochemical dynamics	Ecological systems and dynamics	Earth system history	Human interactions	Solid Earth processes	Solar influences
Role of clouds	Bio/atm/ocean fluxes of trace species	Long-term measurements of structure/function	Paleoclimate	Database development	Coastal erosion	EUV/UV monitoring
Ocean circulation and heat flux	Atm processing of trace species	Response to climate and other stresses	Paleoecology	Models linking: population growth and distribution energy demands change in land use industrial production	Volcanic processes	Atm/solar energy coupling
Land/atm/ocean water and energy fluxes	Surface/deep water biogeochemistry	Interactions between physical and biological process	Atmospheric composition		Permafrost and marine gas hydrates	Irradiance (measure/model)
Coupled climate system and quantitative links	Terrestrial biosphere nutrient and carbon cycling	Models of Interaction feedback, and response	Ocean circulation and composition		Ocean/seafloor heat and energy fluxes	Climate/solar record
Ocean/atm/cryosphere interactions	Terrestrial inputs to marine ecosystem	Productivity/resource models	Ocean productivity		Surficial processes	Proxy measurement: and long-term database
			Sea level changes		Crustal motions and sea level	
			Paleohydrology			

Increasing priority (vertical arrow, upward)

Increasing priority (horizontal arrow, leftward)

NOTE: aim-atmosphere; EUV/UV—extreme ultraviolet/ultraviolet.

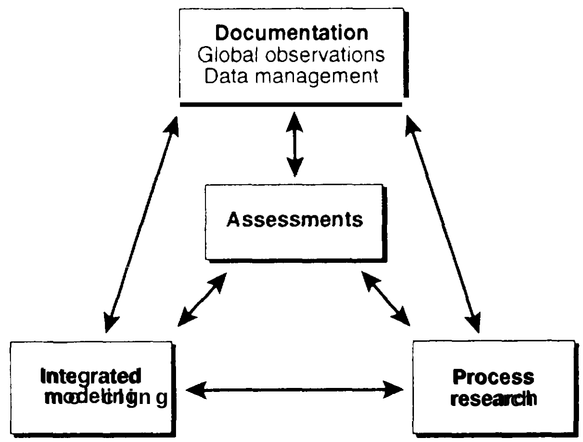
SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1993 U.S. Global Change Research Program* (Washington, DC: CEES, 1992).

related assessments on environmental impacts, technologies for adaptation and mitigation, risk assessment, and policy-response strategies (12). Although the FY 1994 budget proposal reflects these changes, it is unclear how much money agencies will allocate for assessment and how the assessments will be structured. The FY 1994 budget does not show Assessment separately but, rather, embeds it within the other three activity streams. Comprehensive assessments cannot be carried out without expanding the ecological and socioeconomic aspects of the program and incorporating impacts research into it. The FY 1994 budget does not reflect any significant expansion in these areas.

Nonetheless, the Administration has expressed interest in significantly broadening the program to include studies of environmental and socioeconomic impacts and of mitigation and adaptation strategies. "The development of a successful assessment activity in the USGCRP will, I believe, go far toward demonstrating the Clinton-Gore administration's commitment not only to research but to effective action to manage this Nation's national and international environmental policy' (19). If this research materializes, it could then be integrated with research on Earth system processes to conduct integrated assessments. The expanded program should be reflected in the FY 1995 USGCRP budget.

To ensure progress in each of the activity streams, timetables and milestones have been included in each agency's USGCRP research program, although they have not appeared in any published document. These milestones, specified for both the near term (5 to 10 years) and the long term (10 to 30 years), "will guide program and budget development and serve as a critical element in evaluating program accomplishments and progress' (11). The Office of Management and Budget (OMB) could hold research programs to these targets only if the milestones are clearly stated and easily measured and, therefore, enforceable. Representative George Brown, chairman of the Committee on Science, Space, and

Figure 3-3-Functional Architecture of USGCRP



SOURCE: Committee on Earth and Environmental sciences (CEES), *Our Changing Planet: The FY 1993 U.S. Global Change Research Program* (Washington, DC: CEES, 1992).

Technology, has suggested building performance guidelines into authorizing legislation as well as mandates that would redirect or terminate programs that do not make sufficient progress toward stated goals (2).

The Interface Between Policy and Science

Research programs intended to be relevant to management and policy making often fail because of fundamental tensions among researchers, resource managers, and decisionmakers. These tensions are created because of conflicts in the time horizons of each group, differences between priority- or goal-setting processes, and differences in the agendas of extramural research organizations (e.g., universities, industries, and independent laboratories), mission-oriented agencies, and Congress.

The timetable for governmental decisions is driven primarily by the annual budget cycle and an election cycle that ranges between 2 and 6 years. Not surprisingly, policy makers funding global change research often have a shorter time horizon for "answers" than do researchers. This disparity leads to tension between Government officials, who are required to formulate annual budgets and make immediate decisions, and the scientific community, whose long-term research is dependent on continuous and reliable funding. When the questions of policy makers are not answered in one or even a few years, it may become more difficult to sell a program as relevant to policy needs. Mission-oriented agencies are repeatedly deflected by the 'crisis-of-the-month' syndrome, which siphons resources away from long-term programs (37). The result may be annual budget fluctuations and/or rapidly shifting priorities-both of which are detrimental to the development of a sound scientific program. A balance between continuity in priorities and funding and flexibility in project direction is essential (3).

Tension arises between extramural research organizations and the Federal Government because of different research agendas. Universities and independent laboratories judge their scientists to a large extent on their ability to raise funds for research. Adherence to management- and policy-relevant goals is not seen as important unless it leads to more Federal funding.

Many scientists believe that the science must be "complete" before policy conclusions can be made safely. Policy makers, on the other hand, cannot afford the luxury of complete information. Decisions about reauthorizing environmental legislation and natural resource planning and management will continue to be made based on the best available information. "[I]f policy is to be effectual, then we must make policy while we continue to investigate the physical and societal effects of global warming. But this means that policy will also enter the feedback loop, influencing societal responses and physical effects' (30). Science need not proceed in a sequential fashion. Research on the climate system need not be "complete" before research on the ecological effects of climate change is undertaken nor does research on the ecological effects of climate change need to be ''complete' before research on the societal impacts of and potential responses to climate change is initiated (45). If USGCRP is to address policy-relevant questions, a parallel approach to climate effects and response research is necessary.

In a narrow sense, USGCRP is policy-relevant if the most important policy concern is to gain a better understanding of Earth system processes in order to predict climate change. However, the major international assessments conducted by IPCC demonstrate that the key questions policy makers need to address move far beyond the narrow definition of ''observe, document, and predict" global change, into the realm of issues related to adaptation and mitigation. As a result of focusing research funds on climate prediction, USGCRP is not addressing other key science issues or broad policy questions for the near term. For example, what plants and animals are sensitive to climate changes? How might biota and vegetation respond to changes in climate? What are the implications for forestry, agriculture, and natural areas? What mitigation strategies would slow climate change the most? How much would they cost? To whom? How might society respond to changes in climate and global ecosystems? What technologies should be developed? How will the effects of climate change interact with other global environmental changes? How important is climate change in the scheme of long-term environmental threats? How can natural resources be managed to minimize economic and ecological loss? These issues were largely excluded from USGCRP to keep it primarily driven by the earth sciences. Even if accurate regional climate predictions could be given today, land managers, planners, decisionmakers, and policy makers would not have all the information they need to guide their response (33). As originally envisioned in 1990, these issues were to be addressed under the CEES Working Group on Mitigation and Adaptation Research Strategies (MARS), which was abolished in 1992.

If USGCRP begins to address this broader set of questions, it will be moving closer to policy-relevant research. Some fear that a program driven by policy concerns will undermine or

Table 3-l—List of Departments and Agencies or Bureaus Involved in USGCRP Research

DOC	Department of Commerce	
	NOAA	National Oceanic and Atmospheric Administration
DOD	Department of Defense	
	CRREL	Cold Regions Research and Engineering Laboratory
	ONR	Office of Naval Research
DOE	Department of Energy	
	OHER	Office of Health and Environmental Research
DOI	Department of Interior	
	BIA	Bureau of Indian Affairs
	BLM	Bureau of Land Management
	BOM	Bureau of Mines
	BOR	Bureau of Reclamation
	FWS	Fish and Wildlife Service
	NPS	National Park Service
	0 s	Office of the Secretary
	USGS	U.S. Geological Survey
EPA	Environmental Protection Agency	
	ORD	Office of Research and Development
HHS	Department of Health and Human Services	
	NIEHS	National Institute of Environmental Health Services
NASA	National Aeronautics and Space Administration	
	OSSA	Office of Space Science and Applications
NSF	National Science Foundation	
	BIO	Directorate for Biological Sciences
	GEO	Directorate for Geosciences
	SBE	Directorate for Social, Behavioral, and Economic Sciences
SI	Smithsonian Institution	
	IC	International Center
	NASM	National Air and Space Museum
	NMNH	National Museum of Natural History
	NZP	National Zoological Park
	SAO	Smithsonian Astrophysical Observatory
	SERC	Smithsonian Environmental Research Center
	STRI	Smithsonian Tropical Research Institute
TVA	Tennessee Valley Authority	
	RBO	River Basin Operations
USDA	Department of Agriculture	
	ARS	Agricultural Research Service
	CSRS	Cooperative State Research Service
	ERS	Economic Research Service
	FS	Forest Service
	Scs	Soil Conservation Service

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY* 1993 *U.S. Global Change Research Program* (Washington, DC: CEES, 1992).

change the direction of science. Others maintain that the second set of policy-relatd questions can be addressed adequately by research driven by the earth sciences. Maintaining the long-term policy relevance of scientific research under USGCRP will require a formal and iterative assessment link that simultaneously transfers scientific research results in policy-relevant language to decisionmakers and policy concerns to the research community.

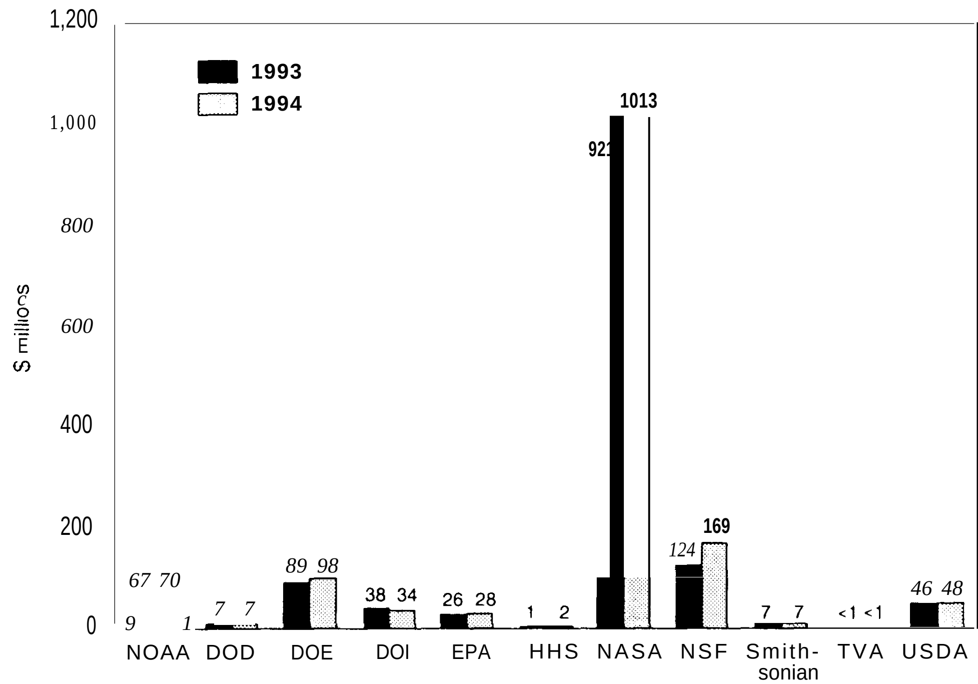
PRIORITIES AND BALANCE IN USGCRP

Budget

CEES designed USGCRP as a cohesive, integrated research program that would encompass the unique attributes of 11 Federal agencies, including 31 bureaus, but it did not assign a central management body (see table 3-l). The priority scheme set up by the three activity streams and the seven science elements is intended to guide budget decisions, and, to date, finding levels have followed these priority areas.

Since the program formally began in FY 1990, the USGCRP budget has grown from $660 million in its first year to $1.33 billion in FY 1993 (7, 9). The proposed budget for FY 1994 is $1.47 billion (8). The budget can be analyzed in terms of distribution across agencies, activity streams, and science elements (see figs. 3-4, 3-5, and 3-6). In FY 1993, projects funded by the National Aeronautics and Space Administration (NASA) comprised 69 percent of the program's budget ($921 million) while projects funded by the Department of the Interior (DOI), which contains most of the land-management agencies, comprised 3 percent of the program's budget ($38 million). For FY 1994, the requested budget for DOI's global

Figure 3-4—U.S. Global Change Research Program Budget by Agency



NOTE: For definition of terms, see table 3-1. FY 1994 values are the requested, not the appropriated, amounts.

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1994 U.S. Global Change Research Program* (Washington, DC: CEES, 1993).

change research program decreased to 2.3 percent of the total.

Of the activity streams, Documentation, including observation and data management, received 45 percent of the budget ($595 million) in FY 1993. Earth Process Research for understanding climate change received 46 percent of the budget ($610 million), and Integrated Modeling and Prediction received 9 percent of the budget ($121 million).[10]

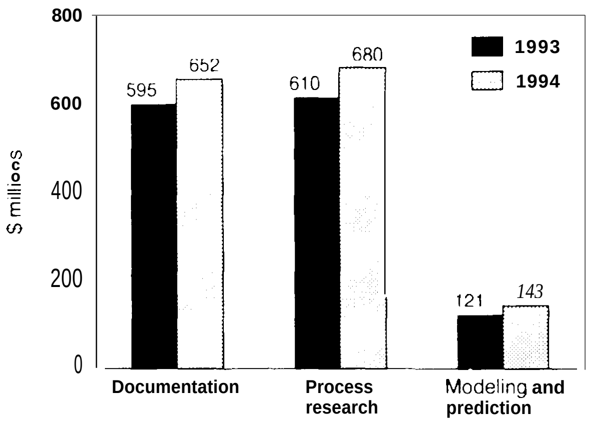
Although USGCRP programs include projects on almost every aspect of climate change, the bulk of the funds is focused on answering scientific questions related to understanding the physics and chemistry underlying climate systems. Research on Climate and Hydrologic Systems and Biogeochemical Dynamics constituted about 71 percent of the program's FY 1993 budget ($937 million). Ecological Systems and Dynamics received 17 percent of the budget ($224 million). The remaining 12 percent of the budget ($165 million) was divided among the remaining four research elements: Earth System History, Human Interactions, Solid Earth Processes, and Solar Influences (8).

Projects are categorized as *focused--directly* relating to global change--or *contributing*—justified on a basis other than global change but having the potential to contribute to the global change knowledge base (see fig. 3-7).[11] Even when both focused and contributing research are considered, 70 percent of all funds is targeted for

10 Most of the funds for modeling and prediction go toward nonmodeling process research. The major modeling groups have received only a small portion of these funds.

11 Unless specifically no@ budget figures refer to the focused budget.

Figure **3-5—USGCRP** Focused Budget **by** Activity Stream



NOTE: Total budget does not Include one-time appropriation of $5million for the State Department in FY 1993 because the distribution of funding among proposed projects is still being determined. The budget for the FY 1994 Assessment activity stream is embedded in the otherthree activity streams. FY 1994 values are the requested, not the appropriated, amounts.

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1994 U.S. Global Change Research Program* **(Washington, DC: CEES, 1993).**

projects in the first two priority research areas. There are no standardized criteria for classifying contributing research, and each agency uses its own system. Consequently, it is difficult to know precisely the extent of contributing research or to get a comprehensive picture of relevant research. Both focused and contributing programs are considered in a procedure called the ''budget crosscut. " USGCRP is one of only a few Federal programs that uses a budget crosscut as a coordinating mechanism. This approach has been reasonably successful in facilitating cooperation and securing new funding for global change research. The USGCRP budget-crosscut process works as follows.

Each program within an agency submits new projects to the appropriate subworking group of CEES. This subworking group determines whether to recommend to the agency that the project be included in USGCRP (projects can be added later in the budget process, but this is the most likely step at which new projects are added).

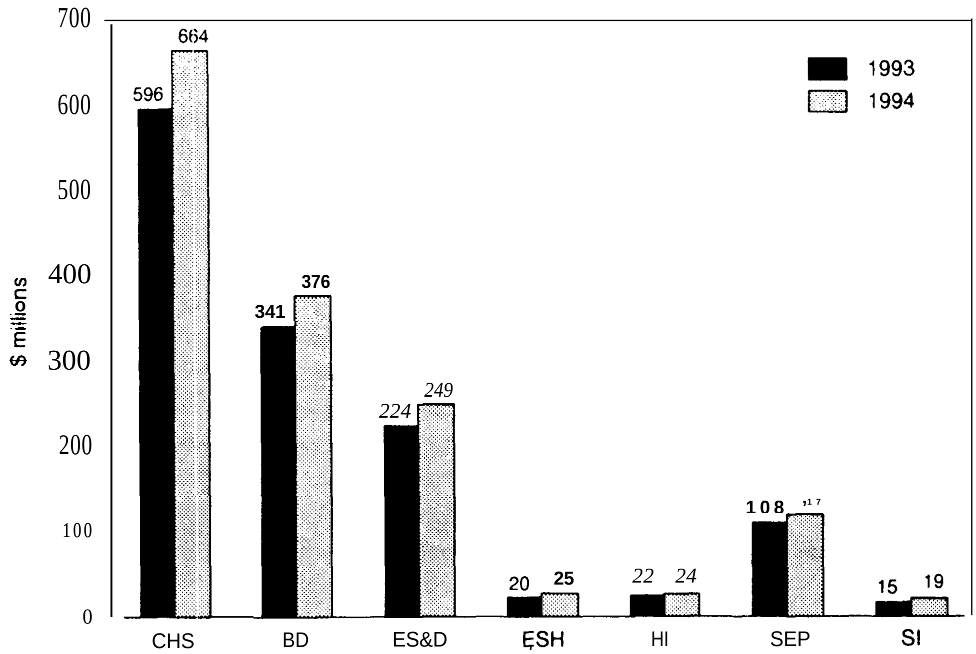
Each agency that participates in USGCRP then develops its own GCRP budget, with some coordination between agencies for joint projects. These budgets are then submitted to CEES, which may continue to negotiate with the agencies. CEES submits one budget proposal incorporating programs from all participating agencies to the Office of Management and Budget (OMB). When the proposal reaches OMB, it is initially reviewed at one meeting by all of the budget examiners for the various agencies involved in USGCRP. Although one examiner takes the lead for USGCRP, the participation of the other examiners is critical because each must understand the purpose of the USGCRP projects that fall within his or her agency's budget. The USGCRP budget is returned to each agency when that agency's whole budget is returned. At that point, deliberations between OMB and the agencies proceed as normal. As agencies work to meet OMB-established budget targets, they look at modifying all projects-they can accept or reject OMB'S recommendations and reprogram their global change budgets.[12] The final USGCRP budget is presented to Congress along with the annual Presidential Budget Request.[13] When the program first started, approximately 70 percent of the proposed budget consisted of research funds from already existing projects.

The USGCRP budget falls within the jurisdiction of several congressional authorization and appropriations committees and subcommittees (see table 3-2). With all of these committees reviewing components of the USGCRP budget, it

12 During the first few years of the program, USGCRP required agencies to ''fence off,'' or commit, their global change research budget requests to the program. They could not reprogram this money later *if* OMB *cut* overall agency funding further down the line.

13 The first two budget requests were long, detailed documents accompanied by executive summaries, but since FY 1992, only the summaries have been published. USGCRP staff determined that the information in the detailed budgets changes slowly and, therefore, needs to be published only every 5 years.

Figure 3-6—USGCRP Budget by Science Element



NOTE: CHS–Climate and Hydrologic Systems; BD–Biogeochemical Dynamics; ES&D–Ecological Systems and Dynamics; ESH–Earth System History; H-Human interactions; SEP–Solid Earth Processes; SI–Solar Influences. FY 1994 values are the requested, not the appropriated, amounts.

SOURCE: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1994 U.S. Global Change Research Program* (Washington, DC: CEES, 1993).

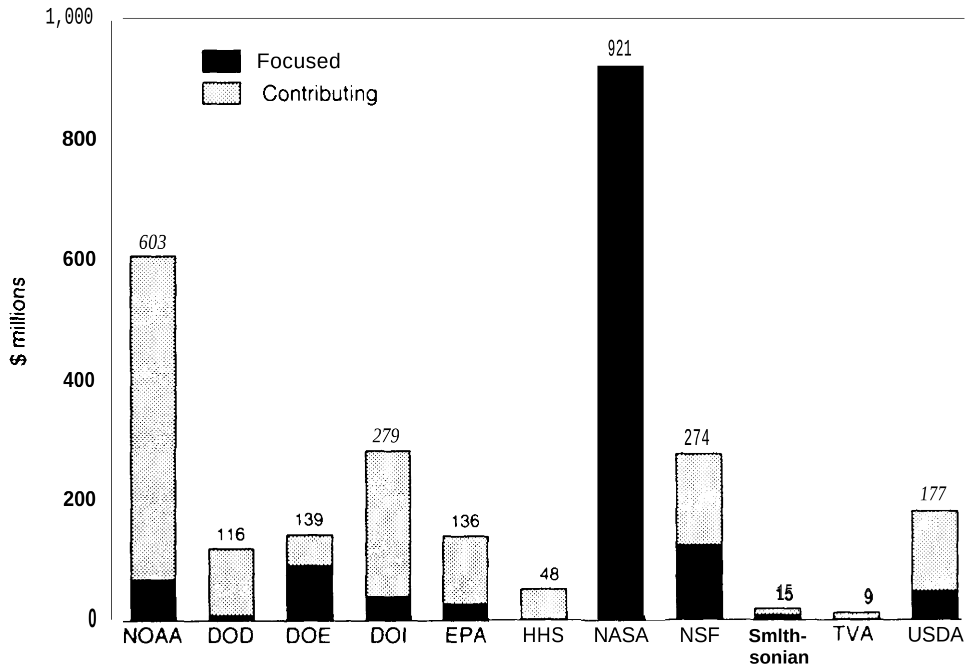
is much more difficult for Congress to consider the USGCRP budget as a whole than it is for the executive branch to do so. Several members of Congress have complained about the fragmentation of congressional attention to the USGCRP budget, but no alternatives have been proposed. It might be useful for Congress to consider using an ad hoc appropriations subcommittee consisting of members from the committees with primary jurisdiction over elements of USGCRP to review the program's budget as a comprehensive unit. If two or three agencies are cooperating on a single project, but one agency does not receive funding for it, the entire project could beat risk.[14] Large, interagency programs such as USGCRP will require innovative methods of funding if they are to succeed.

■ Satellite vs. Nonsatellite Measurements

NASA's Mission to Planet Earth (MTPE) program accounts for over 60 percent of USGCRP focused funding (crossing several of the priority research areas). The core of the MTPE program is the development and maintenance of the Earth Observing System (EOS), an ambitious satellite program originally designed to provide

14 For example, at OTA's workshop "EOS and USGCRP: Are We Asking and Answering the Right Questions?" (Feb. 25-26, 1993), participants cited program such as the World Ocean Circulation Experiment (WOCE), Tropical Oceans Global Atmosphere (TOGA), and the Joint Global Ocean Flux Study (JGOFS)(50). All three are interagency research programs where the success of the entire program depends on contributions from NASA, the National Oceanic and Atmospheric Administration, and the National Science Foundation. However, in a recent budget cycle, NASA received more than it asked for these programs while NOAA and NSF received no money. Rather than kt the programs die, NASA filled the financial gap left by inadequate funding for NOAA and NSF.

Figure 3-7—FY 1993 USGCRP Budget of Focused and Contributing Programs by Agency

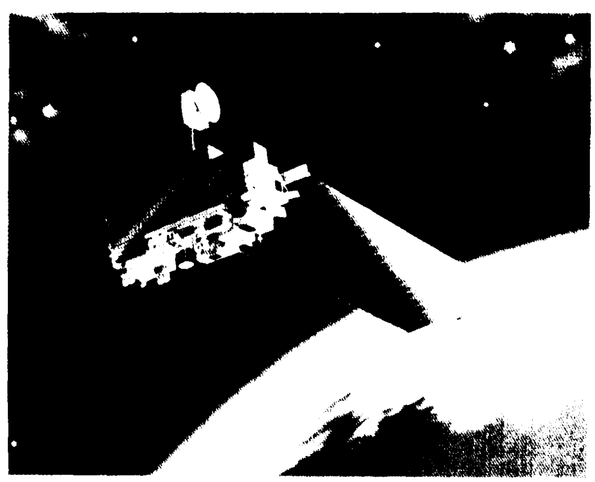


NOTE: For definition of terms, see table 3-1.

SOURCES: Committee on Earth and Environmental Sciences (CEES), *Our Changing Planet: The FY 1993 U.S. Global Change Research Program* (Washington, DC: CEES, 1992); Office of Technology Assessment 1993.

data over a 15-year period related to the study of precipitation; ocean circulation; sources and sinks of greenhouse gases; changes in land use, land cover, hydrology, and ecology; changes in glaciers and ice sheets; ozone; and volcanic activity. Because of EOS'S central role in NASA's USGCRP effort and the great expense of putting satellites in space, the USGCRP budget as a whole is heavily weighted toward satellite-based measurements.[15]

EOS has suffered extensive restructuring over the past few years, which may jeopardize the quality of information gained from remaining EOS instruments. Some instruments that were supposed to have improved the understanding and observation of possible climate change impacts



MARTIN MARIETTA ASTRO SPACE

Artist's conception of NASA's Earth Observing System (EOS). EOS (AM-1 Platform) is scheduled to be launched in 1998.

[15] Although about 50 percent of NASA's USGCRP budget is classified as nonsatellite programs, most of these support data maintenance and operation of the satellite programs.

Table 3-2--Congressional Authorization Committees and Appropriations Subcommittees with Significant Legislative Authority over Agencies with a USGCRP Component

House and Senate Authorization Committees	Jurisdiction [a]
House	
Agriculture	USDA
Armed Services	DOD, DOE
Energy and Commerce	DOE, HHS
Natural Resources	DOE, USDA/FS, SI
Sciences, Space, and Technology	NASA, NSF, DOE, EPA, NOAA, SI
Public Works and Transportation	NOAA, SI
Merchant Marine and Fisheries	USDA, NOAA, SI
Senate	
Agriculture, Nutrition, and Forestry	USDA
Armed Services	DOD, DOE
Commerce, Science, and Transportation	NSF, NASA, NOAA
Energy and Natural Resources	DOE, DOI
Labor and Human Resources	DOE, DOI, HHS
Environmental and Public Works	EPA, SI
Rules and Administration	SI
House and Senate Appropriations Subcommittees	
Labor, Health and Human Services, and Education	HHS
Housing and Urban Development and independent Agencies	NASA, NSF, EPA
Energy and Water Development	DOE
Interior and Related Agencies	DOE, USDA, DOI, SI
Agriculture and Rural Development[b]	USDA
Commerce, Justice, State, and Judiciary	NOAA
Defense	DOD

[a] For definition of terms, see table 3-1.

[b] The corresponding subcommittees of the Senate and House Committees on Appropriations have the same name with one exception: the Senate Subcommittee on Agriculture, Rural Development, and Related Agencies and the House Subcommittee on Rural Development, Agriculture, and Related Agencies,

SOURCES: U.S. Congress, Office of Technology Assessment (OTA), *Federally Funded Research; Decisions for a Decade,* OTA-SET-490 (Washington, DC: Government Printing Office, May 1991); Office of Technology Assessment, 1993,

have been dropped or postponed. For example, the High Resolution Imaging Spectrometer (HIRIS), an instrument potentially capable of resolving some of the more subtle aspects of ecological change that cannot be detected by satellites today, was originally scheduled to be part of EOS, but was dropped during program restructuring (54). EOS began as a $30 billion program, but was scaled back to an $8 billion program (see box 3-A).[16]

Most participants at OTA's workshop "EOS and GCRP: Are We Asking and Answering the Right Questions?" agreed that had EOS been designed initially to be an $8 billion program, it likely would be different from the program we have today. All acknowledged that much good data will be collected and good science will be done through EOS, but that it will provide neither the continuous, multidecade data set necessary for ecosystem studies nor a true global monitoring

16 For more discussion of EOS, see references 49 and 50.

Box 3-A-Remote Sensing as a Tool for Coping with Climate Change

Remote sensing is the observation of the Earth from a distance. The ability to view and monitor large areas of the Earth has become valuable in understanding regional and global-scale phenomena such as weather systems, deforestation rates, and, most recently, climate change. Remote sensing can help reduce the uncertainties associated with climate change in two ways: 1) by improving climate predictions through better understanding of atmospheric and climate processes and 2) by improving scientists' ability to detect and predict the effects of climate change on the biosphere. Both uses of remote sensing would be important for coping with climate change. However, most biosphere-related climate research to date has focused on the former, whereas relatively little has focused on the latter. This box examines the uses and limitations of remote-sensing technologies for observing, detecting, and understanding changes in the biosphere resulting from climate change, land-use change, or other factors.

Development of remote-sensing technology

Airborne sensors-The oldest form of remote sensing-invented about 100 years ago--consists of photographs taken from balloons. The development of the airplane made aerial photography the primary way to monitor and study the Earth's surface from a distance. Scientists also discovered t hat images created from other parts of the electromagnetic spectrum (i.e., the infra red region) could provide additional information about surface characteristics, such as mineral composition, soil moisture, and crop condition.

The U.S. Forest Service has been using aerial photography since the 1930s to measure the area of forests, monitor forest health, and plan timber harvests. Aerial photography is also an important tool in the U.S. Fish and Wildlife Service's National Wetland Inventory Program The technique is best suited for observing relatively small areas and for studies requiring a high level of spatial detail. Riparian wetlands and wetlands less than 5 acres (2 hectares)[1] in area, for example, cannot be accurately characterized by satellite-based observations (18). Therefore, aerial photography is an essential tool for comprehensive wetland monitoring.

However, using aerial photography to get consistent coverage overlarge areas for regional analysis is very difficult and costly. The aerial photography technology used frequently by the National Aeronautics and Space Administration (NASA) for ecological studies can cost about $10,000 per flight. Difficulties also lie in determining exactly where the plane is in space so that the area being photographed can be precisely identified. Also, taking photographs at different times from exactly the same vantage point is difficult. Although aerial photography may be preferable for ecological applications requiring high levels of detail (e.g., wetland inventory and forest monitoring), it is not practical for routine, regular measurements or for studies of large-scale ecological phenomena.

Remote sensing from satellites--By the late 1960s, advances in technology made transmitting electronic images to Earth from satellite-based instruments practical. Polar-orbiting satellites (orbits pass over both the North and South Poles) allow imaging of the entire globe. These Earth observation satellites are equipped with various sensors that detect natural radiance (electromagnetic waves emitted by surface features) and reflectance (those reflected from Earth's surface).[2] The intensity and wavelength of the signal detected become a type of signature for certain surface features. By combining these signals, various vegetation types and other characteristics can be identified.

1 To convert acres to hectares, multiply by 0.405.

2 Sunlight is absorbed by Earth's atmosphere, scattered and reflected off Earth's surface, or absorbed by its surface. Surface features that absorb some waves can re-emit electromagnetic signals-often at longer wavelengths. In general, reflected (or scattered) signals give information about the structure of the surface features, and radiated signals give information about Its chemical composition.

(Continued on next page)

Box 3-A-Remote Sensing as a Tool for Coping with Climate Change--(Continued)

Satellites include several instruments that monitor Earth with "passive sensors" designed to detect a narrow range, or window, of various parts of the electromagnetic spectrum. These windows are called ***spectral bands.*** By detecting different parts of the spectrum, a variety of signatures is obtained. Being able to detect narrower bands improves the ability to categorize detected signatures by wavelength. More narrow bands over a wider range of the spectrum enables detection of more signatures, which improves the ability to discern closely spaced objects and identify surface features. Identification of a wetland, for example, generally requires analysis of three or more infrared spectral bands (18): one discriminates amounts of vegetation, water, and soil moisture; another helps **determine water** quality; and another helps to classify different vegetation types. However, detailed geographic and spectral resolution is more expensive, requires higherdata-collection rates, and limits spatial coverage (49). Passive optical sensors detect only surface features. They cannot be used for Earth observation through clouds, accurate measurement of soil moisture through dense vegetation cover, or detection of submerged vegetation. Radar instruments have "active" sensors that provide their own illumination via microwave pulses and then measure the reflected energy. Unlike optical sensors, radar data can be acquired through clouds and at night. Radar signals are especially sensitive to water and may improve the way soil and vegetation moisture are measured (53, 54). In addition, radar can probe to greater depths and may provide better information about surface roughness, canopy height, and, perhaps, vegetation beneath a dense canopy than can optical sensors (53,54).

Several countries besides the United States, including France, Japan, India and Russia, have launched satellites for environmental studies and Earth observation. Discussed below are satellites whose data are most widely used by US. scientists for detecting change in the biosphere and for large-scale ecosystem studies.

Advanced Very High Resolution Radiometer (AVHRR)--This scanning radiometer, aboard NOAA's Polar Orbiting Environmental Satellite (POES), uses five detectors to create surface images in five spectral bands (49). AVHRR data allow multispectral analysis of vegetation, clouds, lakes, coasts, snow, and ice and have been used to monitor crop conditions, classifyglobal vegetation, and demonstrate the scale of deforestation in the tropics (44). AVHRR provides daily coverage of the Earth, allowing frequent monitoring of a large region and the creation of virtually cloud-free images at a fraction of the cost and computing time required for aerial photography or other satellite technologies (43).[3] Although AVHRR data have much lower spatial resolution than do data from aerial photography--about 0.7 miles (1.1 kilometers)[4] per pixel, or data point--O.6-mile to 16-mile resolutions are adequate for "assessing many global or regional trends in land cover, vegetation damage, deforestation, and other environmental conditions" (44).

Landsat--In 1972, NASA launched the first of a series of Landsat satellites for civilian Earth observation and monitoring. Now, a 20-year continuous data set has been acquired for some selected areas (primarily in the United States and the former Soviet Union), making Landsat data the primary source of data for detecting long-term ecological trends. This long-term record is just now beginning to provide valuable information about trends and changes In wetland area, vegetation types, forest growth, deforestation rates, and urban expansion.

Consistency in measurement is very important for maintaining accurate and useful long-term records. Landsat missions have been designed so that data from different missions can be compared while allowing moderate advances In technology. Sustaining Landsat missions and maintaining a continuous data set over 20 years has not been easy. Over this time, operation of Landsat has changed from public to private and back to public

3 The EROS Data Center makes global data sets that are almost aloud-free by imaging over approximately 10 days.

4 To connvert miles to kilometers, multiply by 1.609.

hands.[5] These changes have threatened to limit the availability of data to users, have increased the costs of data to users, and have limited the number of scenes imaged. Landsats 4 and 5 have already surpassed their expected life spans by several years. The recently launched Landsat 6 (October 1993) never reached orbit, and the long-term Landsat record is now threatened.

The main advantage of Landsat and similar satellites is that they can distinguish surface features with higher spatial and spectral resolution and broader spectral coverage than do AVHRR data.[6] Landsat data have been used to identify and monitor crops, classify forest stands with finer classification scales, and assess damages from natural disasters. However, Landsat provides less frequent coverage of an area (every 16 days) and requires more computing time and power than do AVHRR data sets. For these reasons, AVHRR is more widely used than Landsat for global data analyses. Landsat data sets are also significantly more expensive than are AVHRR data sets. According to one scientist, "The 10-times greater expense and 1,000-times-greater data volume [of Thematic Mapper of Landsat (TM) data as opposed to AVHRR data preclude] use of multiple annual [Landsat] data sets for global studies" (43). (The cost of each 120-by 110-mile scene is about $5,000 (18)).

New technologies[7]—instruments considered for Landsat 7 will improve surface resolution and allow the creation of topographic images (by having the ability to point to the side), thereby increasing Landsat's revisit frequencies from once every 16 days to once every 3 days (49). Until recently, a High Resolution Imaging Spectrometer (HIRIS) was under consideration for development as part of NASA's Earth Observing System (EOS) program. In principle, HIRIS data could be used to detect specific species of trees or other ground cover, track pollutants in water, and identify natural vegetation that is under stress. A Synthetic Aperture Radar (SAR) proposed for EOS--but recently canceled--would have been capable of multiangle, multifrequency, and multipolarizartion measurements (49). SAR could have measured soil moisture under vegetated land, determined the vertical structure of vegetation canopies, and measured canopy moisture (53). However, both HIRIS and SAR were dropped from consideration because of high costs and launch requirements (54).

Uses of remote sensing under climate change[8]

Many questions about climate change impacts and how to respond to them remain unanswered. For example, which plant and animal communities are likely to change first? How will they change? How fast will changes occur? Which species are already declining? Why? Where? Which are flourishing? Satellite data are already being used to answer many questions related to large-scale ecological change, but limitations in both satellite technology and in ecological understanding prevent some of the most compelling questions about global ecological change from being addressed with satellite data. The table in this box (next page) lists some potential uses of remote-sensing data.

Remote sensing for scientific study-Although an Earth observation satellite has never been launched specifically for ecological studies (41), current operating satellites can help reveal some important aspects of

5 Landsat 4 and 5 are operated and maintained by the Earth Observation Satellite Company (EOSAT, a private company. Landsat 6 will be launched by the U.S. Government but operated by EOSAT (16). The Land Remote Sensing Policy Act of 1992 (P.L. 102-555) transfers all control of future Landsat missions (starting with Landsat 7) to the Department of Defense and NASA (49).

6 Landsat4 and 5 carry the Thematic Mapper (TM) sensor, providing 100-foot (30-m) ground resolution in six spectral bands (one thermal infared band has a 390-foot (120-m) resolution). Landsat 6 is scheduled for launch on September *5,1993,* and will carry an Enhanced Thematic Mapper Imaging Instrument (ETM). ETM will improve the TM by adding a 5-foot resolution panchromatic sensor, making it possible to collect data streams with sharper resolutions and increase vegetation discrimination.

7 See *The Future of Remote Sensing from Space: Civilian Satellite Systems andApplications (49)* for a more complete discussion of the future of remote-sensing technologies.

8 Much of this section was developed from a workshop, "Ecology and Remote Sensing," held September 18, 1992, at the University of Maryland at College Park.

(Continued on next page)

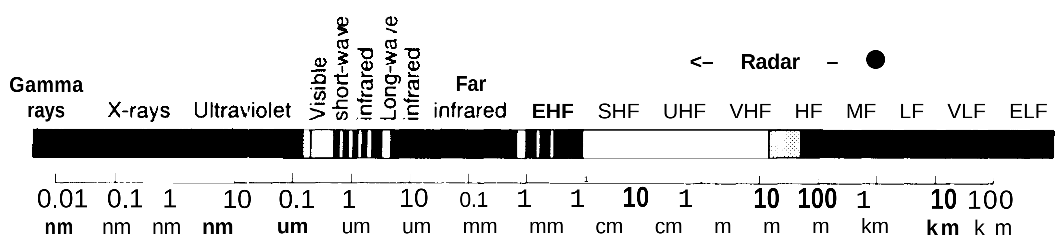
Box 3-A--Remote Sensing as a Tool for Coping with Climate Change--(Continued)

Potential uses of current remote-sensing data for biosphere study
- Classify land-surface cover
- Detect Vegetation- climate relationships
- Detect frequency and extent of fire
- Detect inundation extent
- Detect surface soil moisture in areas of low vegetation cover
- Detect land and ocean surface temperature
- Calculate ocean color indices
- Calculate vegetation indices
- Estimate global net primary production
- Estimate ranges of evapotranspiration
- Measure horizontal canopy structural characteristics
- Measure canopy biochemical constituents
- Measure vegetation water content

Potential uses of future remote-sensing data.[a]
- Classify vegetation cover by community types or species assemblages
- Detect and monitor margins of ecosystems
- Detect successional stages in forests
- Characterize vegetation stress (in natural communities as well as in crops)
- Estimate contaminant concentrations in water and snow
- Estimate biochemical composition of vegetation canopies in more detail
- Estimate canopy structural characteristics with independent methods
- Estimate biomass
- Estimate extent of deforestation
- Measure soil moisture in vegetated areas
- Measure vertical canopy structural characteristics
- Measure canopy biochemical constituents in more detail
- Measure canopy moisture content
- Measure canopy height

a Some uses may require further research in order to be proven.

SOURCES: U.S. Congress, Office of Technology Assessment (OTA), Ecology and Remote Sensing Workshop, Center for Global Change, University of Maryland at College Park, Sept. 18, 1992; U.S. Congress, Office of Technology Assessment (OTA) workshop, ‘EOS and USGCRP: Are We Asking and Answering the Right Questions?” Washington, DC, Feb. 25-26, 1393; S.L. Ustin et al., “Opportunities for Using the EOS Imaging Spectrometers and Synthetic Aperture Radar in Ecological Models,” Ecology, vol. *72, No. 6,1991,* pp. 1934-45; D.E. Wickland, "Mission to Planet Earth: The Ecological Perspective,” Ecology, vol. 72, No. 6,1991, pp. 1923-33.



Most of the energy that is reflected, absorbed, or scattered by the Earth’s atmosphere is visible or shortwave infrared energy (from 0.4 to 4 microns). in the thermal infrared, most attenuation is by absorption. Short-wavelength radiation is reflected by clouds, water vapor, aerosols, and air; scattered by air molecules smaller than radiation wavelengths; and absorbed by ozone in shorter wavelengths (<0.3 micron) and by water vapor at the longer visible wavelengths (>1.0 micron).

SOURCE: A.M. Carleton, Satellite Remote Sensing in Climatology(Boca Raton, FL: CRC Press, 1991).

changing ecosystems and the consequences of various impacts on the biosphere. Most importantly, satellite data have allowed the biosphere to be studied from a new perspective and at much larger scales than ever before, opening up a whole new area of ecological study. The most direct application of satellite data is the detection and study of land-use change. Because satellite data can be used to discern broad classes of vegetation (e.g., grasslands, crops, evergreen forests, and deciduous forests), it has been an important tool in studying the extent of deforestation in the tropics and the extent of desertification in Africa.

Leaf area, which can be calculated from remote-sensing data, has been used for identifying more specific types of vegetation cover of large vegetated areas. A Leaf Area Index (LAI) is being used to identify the extent of specific crops (such as wheat) and their stress levels throughout the growing season. It is also being used to monitor the condition of rangelands, pastures, and other mostly homogeneous land cover. This technique is less useful for natural vegetation where suboptimal growing conditions and a mix of species make t he links among LAl, vegetation type, and health weak.

Remote sensing has also been used to monitor soil-moisture conditions in areas where--and during seasons when--vegetation cover is sparse, but it cannot measure ground soil moisture in heavily vegetated areas. Thus, satellite images ***miss*** most forested wetlands. Coastal erosion and some processes of large, shallow, open wetlands (such as those in the Mississippi River Delta) can easily be studied and monitored over time with remote-sensing data. For adequate delineation of wetlands, many wetland scientists believe that color infrared data at a 16-foot (5-meter)[9] resolution viewed in stereo is required (18). Landsat 7 may be able to get this kind of resolution for wetland delineation, but wetland scientists studying the larger-scale processes of coastal wetlands would rather have a coastal contour map at l-foot contour intervals than improved satellite remote-sensing technology (50).

Remote-sensing data have been used for tipping forest evapotranspiration and photosynthesis-key processes that control the exchange of energy and mass in terrestrial vegetation. Climate change will likely perturb patterns of evapotranspiration and photosynthesis. Regional maps of these processes will help researchers detect and understand such change.

Remote sensing for land-management and planning-Remote-sensing data are being used in conjunction with data from other sources as a tool for land management and planning. For example, the Fish and Wildlife Service launched the Gap Analysis Project (GAP) in 1991 to identify areas of potentially high biodiversity and their protection status to guide future land acquisitions and habitat-protection efforts. Remote sensing (mostly Landsat data) is the primary tool used to identify vegetation types (see vol. 2, box 5J),

In addition, Geographic Information Systems (GISs) have been developed and used throughout Government agencies for regional analyses and planning. Vegetation and land-cover information from remotely sensed data is combined with digitized geologic, geographic, hydrologic, and topographic data in one computer system, so that one overlay containing all this information can be studied and used to test potential land-use decisions (such as altering the hydrology). Such analyses can lead to a better understanding of the Earth's surface and subsurface processes and more sound regional land-use planning near environmentally sensitive areas (see vol. 2, box 5-J).

Ducks Unlimited uses remotely sensed data from satellites in combination with aerial photography from the Fish and Wildlife Service's National Wetlands Inventory project for wetland monitoring. For their purposes, combining National wetlands Inventory digital data with satellite data for evaluating wetland functions is more valuable than using either product alone (18).

Current satellite data are useful for studying ecological processes on a very large scale, but are relatively inadequate for detecting more subtle ecological changes, such as those at ecotones, at the edges of ecosystems, or within an individual plant community. "Satellite data cannot match the extent, classification detail, or reliability" of data from aerial photography and other manual techniques used in the National Wetlands Inventory Project (18).

9 To convert feet to meters, multiply by 0.305.

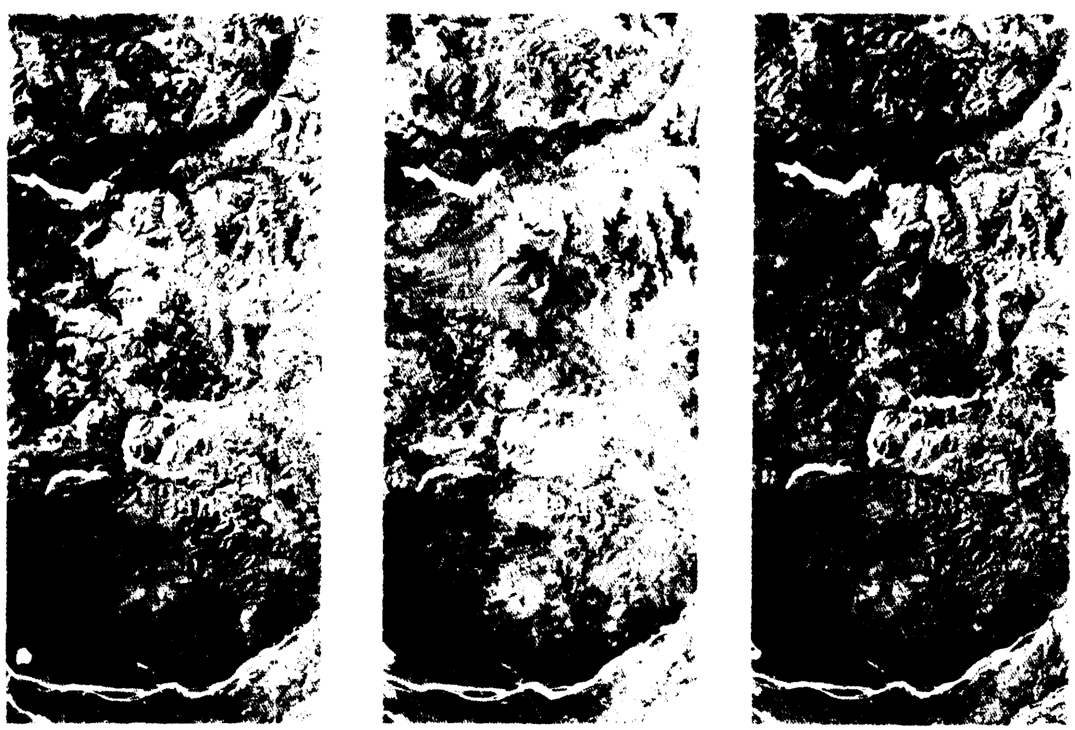
(Continued on next page)

Box 3-A-Remote Sensing as a Tool for Coping with Climate Change--(Continued)

Limitations to broader applications of remote sensing

The principal drawbacks of satellite data for detecting impacts of climate change are their limited spatial and spectral resolution. Remote sensing can be used to determine broad classes of vegetation, but it cannot identify species or communities. With satellite-based information, it is nearly impossible to study the more subtle aspects of regional ecological change. These include vegetation health in natural areas and mixed forests, ecological change at ecosystem boundaries, migration of a single species or even a species community, drought conditions and soil-moisture trends in heavily vegetated areas, and exact rates of wetland loss. Furthermore, few ecologists are skilled at studying ecosystems at large, coarse-resolution scales.

Technology is available to expand applications of satellite remote sensing for studying impacts of climate change, but high costs, launching requirements, and scientific priorities have delayed its development Even current satellite data have not been used to their full potential for studying potential impacts of climate change. For example, large-scale studies of the biosphere are limited by the availability of data sets. The only global vegetation data set available is the Global Vegetation index (GVI), generated from AVHRR data. Even a



Landsat MSS Image
September 15, 1973

Landsat MSS Image
May 22, 1983

Landsat MSS Image
August 31, 1988

LANDSAT/U.S. GEOLOGICAL SURVEY

Landsat data have been used to identify and monitor crops, classify forest stands, and assess damages from natural disasters. These Landsat images of Mount St. Helens show the area in 1973 before the volcano erupted and in 1983 and 1988, after the volcano erupted.

consistent, calibrated, single-source map of U.S. land cover and land use does not exist. More detailed coverage of large areas on the global or continental scale is limited by high costs and data volume. In fact, many university researchers have started to study AVHRR data despite its limited resolution and spectral information because of the high costs of Landsat data.

Another factor that limits wider use of remotely sensed data stems from differences among scientific disciplines. Many ecologists, for example, are not trained to use satellite data (41), and those who use remote-sensing technologies are typically not mainstream ecologists. There has never been a remote-sensing instrument designed specifically for ecological studies (41). Furthermore, few remote-sensing scientists have backgrounds in ecology or biology (41). Ecologists must essentially take what they can get from remote-sensing data that may not be optimal for their field. Opportunities for interdisciplinary studies at universities and the relatively recent surge of interest in ecosystem research (spurred by climate change, deforestation, and global pollution) may help to bridge the gap.

SOURCE: Office of Technology Assessment 1993.

network. Both these shortcomings are important to consider in future discussions about the science base of USGCRP. Many correlative measurements made with airborne platforms or ground-based instruments (that would verify and calibrate the satellite measurements and provide continuous coverage when satellites are not operating) were originally planned to be part of USGCRP but were not funded. Costs for such efforts could be a small percentage of the USGCRP budget—in the tens of millions of dollars each year.[17]

The Landsat satellite monitoring program is of significant ecological interest because it is the primary source of data for detecting long-term ecological trends (18).[18] Landsat satellites contain instruments that analyze multispectral data to obtain images of the Earth (see box 3-A). New technologies have allowed resolution to improve from about 100 feet (30 meters)[19] to a few feet. Landsat data allow changes to be detected in vegetation type and cover, hydrologic patterns, extent of wetlands, land use, and soil moisture. It is the only satellite monitoring program that has a 20-year data set, despite several changes in ownership and new technology over the years that nearly resulted in its termination. The data are just now becoming relevant for ecological studies of changes in vegetation cover due to natural processes. Multidecade data sets are vital to global change research; however, consistency is extremely difficult because the average life of a satellite is only 5 years. A central element of an extended set of missions must be ensuring the compatibility of future satellite data with current data while accommodating new technologies. In addition, subsequent satellites must survive fiscal fluctuations.

■ Balance Among NASA and Other USGCRP Agencies

The question of balance between satellite and nonsatellite measurements is directly connected to the question of balance among participating USGCRP agencies. Currently, NASA, the National Oceanic and Atmospheric Administration (NOAA), and the Department of Energy (DOE)

17 OTA'S workshop "EOS and USGCRP: *Are we Asking* and Answering the Right Questions?' Washington, DC, Feb. 25-26, 1993.

18 Landsat receives approximately 25 percent of its budget from NASA and 75 percent from DOD. It is a part of NASA's Mission to Planet Earth, but it is separate from EOS.

19 To convert feet to meters, multiply by 0.305.

LANDSAT/U.S. GEOLOGICAL SURVEY

This Landsat photo of Yellowstone National Park demonstrates the different land-use patterns in the vicinity of the park. A clear line, formed by different land-use patterns, delineate the park boundary. The area spans three States and is managed by Federal, State, private, and tribal landowners. The Federal portion of the area comprises two National Parks, nine National Forests, and land owned by the Fish and Wildlife Service and the Bureau of Land Management. (See vol. 2, ch. 5, box 5-F.)

control 80 percent of the focused research budget for USGCRP. Even when contributing programs are considered (e.g., those that are ongoing for other reasons), NASA, DOE, and NOAA control 60 percent of the USGCRP budget (see figs. 3-4 to 3-7). The lack of participation by agencies other than NASA has led to gaps in the overall program. For example, DOI, which manages approximately 500 million acres (200 million hectares)[20] of public land that could be affected by climate change, requested a decrease in USGCRP funding for both FY 1993 and FY 1994. This can be attributed partly to management agencies focusing their resources on what they perceive as more immediate management concerns.

Another dimension of the imbalance in agency participation is the historical attraction that Congress and the executive branch have had for space-based research. Federal agencies may correctly perceive that it is easier to get financial support for large, space-based projects than for lower-profile research such as monitoring (36, 55).

NASA's contribution dwarfs contributions from other agencies, but it is unclear how to bring more balance to the program to help fill the gaps and make the necessary links to other global change issues. Because USGCRP does not have a program budget, it would be difficult to redistribute funds across agencies; however, there might be opportunities to modify projects within agencies to help meet the needs of global change research.

ADAPTATION RESEARCH IN THE FEDERAL GOVERNMENT

The Mitigation and Adaptation Research Strategies program was created about the same time as USGCRP and operated as an independent working group under CEES. MARS was conceived to develop 'a coordinated Federal research strategy for mitigation of, and adaptation to, global change and with assessment of economic, social and environmental effects of the proposed responses. The program addressed four functions: mitigation, adaptation, economics, and social dynamics (5). MARS objectives under its adaptation program were to:

1. determine the sensitivity and adaptive capacity of human and other natural systems to global change, and the social, cultural, economic, and other constraints or impediments to implementation of adaptive measures and methods to reduce those constraints;
2. determine the mechanisms and timing required for current evaluation procedures and practices to be modified to meet soci-

[20] To convert acres to hectares, multiply by 0.405.

ety's needs to accommodate global change, given the uncertainties about the timing and magnitude of global change and its effects; and

3. identify, develop, demonstrate, and evaluate technologies and strategies to adapt to global change.

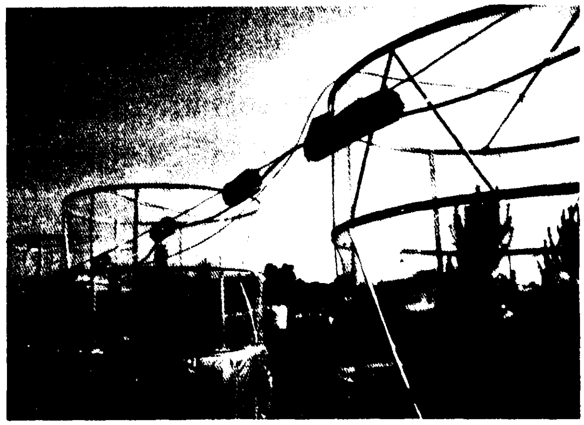
These objectives were to be directed toward water resources; natural systems; food, forestry, and fiber; and human systems. In a sense, MARS was charged with conducting all the research components missing from USGCRP.

However, MARS did not receive the administrative backing that USGCRP did and never developed an interagency research program on mitigation and adaptation research. By 1992, MARS, as a formal entity, ceased to exist. Under the CEES Subcommittee on Global Change, an informal, and later formal, Subcommittee on the Environment and Technology formed in 1992, which continues to address mitigation and adaptation issues, but in a much broader context. Although this subcommittee has no budgetary power, it is holding the door open for agencies with more interest in applied climate change research than in basic research, such as the Environmental Protection Agency, the Department of Housing and Urban Development (HUD), the Tennessee Valley Authority, the U.S. Department of Agriculture (USDA), and the Department of the Interior, to redirect their funds to this end.

Although MARS provided a forum for agencies to discuss global change programs of mutual interest, it was unable to exercise any influence over project selection and funding. Consequently, MARS served primarily to identify existing agency programs and projects that addressed mitigation, adaptation, social dynamics, and economic issues either as a main focus or as a contributing element.

Research "Focused" on Adaptation

MARS classified only a handful of projects as focused on adaptation research, and funding for



U.S. FOREST SERVICE

Three-level, open-top chambers, such as these at Finley Farm, North Carolina, can be used to study the effects of increased carbon d-oxide, ozone, and drought stress on trees and plants.

these projects totaled $8.18 million in N 1992 (5) (see table 3-3A). These projects are not included in USGCRP per se because they do not conform to the USGCRP mission of ''observe, understand, and predict. "

Of the $8.18 million considered focused on adaptation research, NOAA spent $4.1 million, or close to 50 percent, the National Science Foundation (NSF) and EPA each spent $1.2 million, or 15 percent, each, and USDA spent $0.35 million, or 4 percent, of the total spent on adaptation research. DOI, the department that houses land-management agencies responsible for 500 million acres of public land, was conspicuously absent from the MARS list of agencies undertaking focused adaptation research.

Examples of focused adaptation research include: a $200,000 NSF program on the effects of climate change on coastal zones; a $1.1 million USDA program that seeks to simulate the effects of changing climate and management practices on organic matter, crop yields, and rangeland productivity; a $20,000 TVA program on regional climate scenarios; a $30,000 TVA program addressing the sensitivity of the TVA reservoir and power supply systems to extreme meteorology; a $250,000 Department of Defense (DOD) program that assesses the impacts of potential climate

Table 3-3A—FY 1991 and 1992 Focused Research by Agency and Function ($ millions)

Agency[a]	Totals 1991	Totals 1992	Mitigation 1991	Mitigation 1992	Adaptation 1991	Adaptation 1992	Economics 1991	Economics 1992
DOC	3.3	5.1	0.1	1.0	3.2	4.1		
DOD		1.1				1.1		
DOE	1.7	2.2	1.7	2.2				
DOS	<0.1	0.1			<0.1	0.1		
DOT		0.2				0.2		
NSF	1.2	1.2			1.2	1.2		
USDA		3.5		2.1		0.4		1.0
EPA	3.3	3.3	2.4	2,1	1.0	1.2		
Totals	9.5	16.5	4.1	7.3	5.4	8.2		1.0

[a]DOS= Department of State; DOT= Department of Transportation. For definition of other terms, see table 3-1.

SOURCE: Committee on Earth and Environmental Sciences (CEES), Mitigation and Adaptation Research Strategies Working Group, *MARS Working Paper 1: Description of Proposed Cooordinated Program* (Washington, DC: CEES, 1992).

Table 3-3 B--FY 1991 and 1992 Focused Adaptation Research by Agency and Element ($ millions)

Agency[a]	Totals 1991	Totals 1992	Natural Systems 1991	Natural Systems 1992	Human Systems 1991	Human Systems 1992	Food, Forestry, and Fiber 1991	Food, Forestry, and Fiber 1992	Water Systems 1991	Water Systems 1992
DOC	3.2	4.1	0.7	1.1	0.4	1.0			2.2	2.0
DOD		1.1								1.1
DOS	<0.1	0.1	<0,1	0.1						
DOT		0.2				0.2				
NSF	1.2	1.2			1.2	1.2				
USDA		0.4		0.1		0.1		0.1		0.1
EPA	0.9	1.2	0.3	0.4	0.2	0.3	0.2	0.3	0,2	0.3
Totals	5.4	8.2	1.0	1.6	1.8	2.8	0.2	0.3	2.4	3.4

[a]DOS= Department of State; 130 T= Department of Transportation. For definition of other terms, see table 3-1.

SOURCE: Committee on Earth and Environmental Sciences (CEES), Mitigation and Adaptation Research Strategies Working Group, *MARS Working Paper I: Description of Proposed Coordinated Program* (Washington, DC: CEES, 1992).

change on water resource management; and a $50,000 DOE program on regional impacts that seeks to develop a model designed to capture the essential climate-sensitive relationships within and between resource sectors (6).

Research that MARS classified as focused on economics received $1.0 million in FY 1992; no research was classified as focused on social dynamics.

Research "Contributing" to Adaptation

MARS identified research on the effects of climate change on natural and engineered systems and research on the potential impact on society of these changes as contributing to adaptation research. With the exception of NASA's component, the majority of USGCRP research under the science elements Ecological Systems and Dynamics and Human Interactions can be considered impacts research--that is, how climate change effects plants, animals and people. Ecological Systems and Dynamics research made up $224 million, or 17 percent, of the FY 1993 USGCRP budget, and Human Interactions research made up $22 million, or less than 2 percent of the USGCRP budget. NASA spent 66 percent

Table 34A-Percent of Total FY 1992 USGCRP Budget for the Third Science Element, Ecological Systems and Dynamics (ESD), Compared with Percent of Each Agency's GCRP Budget for ESD[a]

Agency	Percent of USGCRP ESD budget allocated or requested[b]		Percent of USGCRP ESD budget allocated or requested as percent of each agency's GCRP budget	
	FY 1993	FY 1994	FY 1993	FY 1994
DOC/NOAA	1	1	5	4
DOD	<1	<1	15	15
DOE	2	2	4	4
DOI	4	3	21	24
EPA	4	4	36	39
HHS	0	0	0	0
NASA[c]	66	66	16	16
NSF	10	12	17	18
Smithsonian	2	2	62	62
TVA	0	0	0	0
USDA	11	10	53	52

[a] ESD received $224,3 million in FY 1993; for FY 1994, the budget request is for $249.3 million (approximately 17 percent of the total USGCRP budget).
[b] FY 1993 figures represent appropriated funds; FY 1994 figures represent requested funds.
[c] Part of the reason the NASA figures are so high is that the capital costs of their projects are greater relative to other projects, Although these comparisons are instructive, they do not reflect information on the cost and yield of research.

Table 3-4 B-Percent of Total FY 1992 USGCRP Budget for the Fifth Science Element, Human Interactions (Hi), Compared with Percent of Each Agency's GCRP Budget for HI[a]

Agency	Percent of USGCRP HI budget allocated or requested		Percent of USGCRP Hi budget allocated or requested as percent of each agency's GCRP budget	
	FY 1993	FY 1994	FY 1993	FY 1994
DOC/NOAA	3	3	1	1
DOD	0	0	0	0
DOE	11	10	3	3
DOI	13	6	7	4
EPA	15	11	13	10
HHS	5	6	100	100
NASA	0	0	0	0
NSF	42	53	8	8
Smithsonian	3	3	10	10
TVA	0	0	0	0
USDA	8	9	3	4

[a] HI received $22.2 million in FY 1993; for FY 1994, the budget request is for $24.4 million (approximately 1.6 percent of the total USGCRP budget).
[b] FY 1993 figures represent appropriated funds; FY 1994 figures represent requested funds.
SOURCE: Office of Technology Assessment, 1993.

of the total USGCRP Ecological Systems and Dynamics budget; however, Ecological Systems and Dynamics research represents only 16 percent of the agency's global change research budget (see table 3-4A). In addition, NASA's research in this area focuses primarily on ecological *functions* and *characterizations,* not *effects* of climate change on ecological systems. In contrast, USDA spends only 11 percent of the USGCRP Ecological Systems and Dynamics budget, which represents 53 percent of their global change research budget. DOI spends 3.5 percent of the USGCRP Ecological Systems and Dynamics budget, which represents 21 percent of their global change research budget (see table 3-4A). The agencies that one would expect to conduct the bulk of research on ecological systems and the effects of climate change on ecosystems—EPA and the land-management agencies of DOI and USDA—play only a minor role. The reasons are varied and complex, but include the higher capital costs of NASA projects and the reluctance of some agencies to actively support and participate in the program. Consequently, these agencies' contributions to USGCRP comprise projects that are in place for reasons other than climate change research, such as characterizing ground- and surface-water flows, maintaining weather data, and monitoring ecosystem change.

Definitions of what encompasses Ecological Systems and Dynamics research become very important in the face of such disparate budget allocations among agencies. If the definition is not consistent across agencies, or if it is too broad, large gaps could potentially exist. For example, it is unclear how much large ecosystem research is being conducted—such as research on the use of corridors for the migration of plants and animals in response to global change or techniques for ecosystem transplantation. Are we clarifying rates at which various species in an ecosystem can migrate? Do we understand how to maintain ecosystems in place? Will pest ranges increase? Will fire hazards increase'? Are our crop and tree varieties genetically diverse enough to cope with the range of potential changes? What agencies are addressing these questions, and is research adequate to find the answers to these questions? What questions under this research category does NASA attempt to answer compared with what questions USDA attempts to answer? NASA's contribution to the understanding of ecological systems comes largely from space-based measurements and observations, whereas the land-management agencies' contribution comes more from field research. Box 3-B highlights weaknesses in environmental research identified by the National Research Council (NRC).

Of the $22 million spent on Human Interactions, NSF spends 42 percent, which represents 7.5 percent of their global change research budget. Except for the Department of Health and Human Services (HI-IS), which spends $5.41 million, or 100 percent, of its USGCRP budget on Human Interactions, the percent of agency USGCRP budgets allocated to Human Interactions ranges from 0 to 10 percent (see tables 3-3B and 3-4B). Although it is difficult to obtain reliable numbers, because social science research has many labels, it is doubtful that any Federal agency devotes as much as 1 percent of its total research budget to environmental social science (37).

Specific projects classified as contributing to adaptation include: a $4.7 million program at DOI's National Park Service (NPS) to improve the scientific basis of adaptive management of the types of ecosystem responses likely to be associated with climate and other global environmental changes; a $1.3 million program at DOI's Bureau of Reclamation (BOR) to study the changes in hydrologic processes under scenarios of global climate change and to determine the potential impacts on snowpack, snowmelt, and runoff in the 17 Western States; a $1.5 million program at DOI's U.S. Geological Survey (USGS) to evaluate the sensitivity of water resources to climate variability and change across the United States; and a $150,000 DOE program to evaluate the existing social science knowledge base concerning energy and the analysis of the role of institutions in making decisions affecting climate change (6).

Very little of the effects research described above could also be considered research on the impacts of global change on human systems. USGCRP'S new Economics Initiative does consider the impact of climate change on the economy, and several agencies support research in this area, including NSF, NOAA, and USDA (in its Economics Research Service). However, the eco-

Box 3-B-Weaknesses in U.S. Environmental Research Identified by the National Research Council

- The research establishment is poorly structured to deal with complex, interdisciplinary research on large spatial scales and long-term temporal scales. These traits characterize the primary needs of an effective environmental research program.
- There is no comprehensive national environmental research plan to coordinate the efforts of the more than 20 agencies involved in environmental programs. Moreover, no agency has the mission to develop such a plan, nor is any existing agency able to coordinate and oversee a national environmental research plan if one were developed.
- The lack of unintegrated national research plan weakens the ability of the United States to work creatively with governments of other nations to solve regional and global problems.
- The Nation's environmental efforts have no clear leadership, As suggested by the lack of a cabinet-level environmental agency, the United States has lacked strong commitment to environmental research at the highest levels of government. Environmental matters have been regarded as less important than defense, health, transportation, and other government functions.
- Although **individual** agencies and associations of agencies analyze data to provide a base for decisions on strategies and actions to address specific environmental problems, no comprehensive "think tank" exists for assessing data to support understanding of the environment as a whole and the modeling of trends whose understanding might help to set priorities for research and action.
- Bridges between policy, management, and science are weak There is no organized system whereby assessments of environmental problems can be communicated to decisionmakers and policy-setters.
- Long-term monitoring and assessment of environmental trends and of the consequences of environmental rules and regulations are seriously inadequate. The United States has a poor understanding of its biological resources and how they are being affected by human activities. Although biological surveys have a long history at the State and Federal level in the United States, it is only very recently that we appear to be approaching a consensus on the need for a comprehensive, national biological survey.
- There is insufficient attention to the collection and management of the vast amount of data being developed by the 20 agencies involved in environmental research. Collection and management of environmental life-science data are less well organized than those of environmental physical-science data.
- Education and training in the Nation's universities are still strongly disciplinary, whereas solution of environmental problems requires broadly trained people and multidisciplinary approaches, Opportunities for broadly based interdisciplinary graduate degrees are few, and faculty are not rewarded as strongly for interdisciplinary activities as they are for disciplinary activities. Thus, there is a risk that environmental scientists appropriately trained to address pressing needs will be lacking.
- Biological-science and social-science components of environmental research are poorly supported, compared with the (still inadequate) support given to the physical sciences.
- Research on engineering solutions to environmental problems is seriously underfunded. That reduces our ability to protect ecosystems and restore damaged ones to productivity and jeopardizes the Nation's ability to achieve major economic benefits that are certain to derive from increasing worldwide use of technologies for these purposes.
- With respect to environmental affairs, government operates in a strongly adversarial relationship with both industry and the general public, to the detriment of integrated planning and maintenance of an atmosphere of mutual trust that is essential for effective government functioning.
- With important exceptions in the National Science Foundation, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey, most environmental research and development is narrow, supporting either a regulatory or a management function. That appears to be particularity true in the environmental life sciences.

SOURCE: National Research Council, Research to Protect, Restore, and Manage the Environment, Committee on Environmental Research, Commission on Life Sciences (Washington, DC: National Academy Press, 1993).

nomics component of USGCRP is not well-integrated with the rest of the program.[21]

CEES is aware of the absence of research on the impacts of climate change and has slightly expanded Earth Process Research, the second integrating priority, to include research to determine the impacts associated with predicted global changes (12). However, explicit recognition of the need for research on impacts of climate change is not yet reflected in the program structure.

A New Adaptation Program

For reasons discussed above, it is necessary to pursue research on impacts of global change and potential response and adaptation strategies without waiting for USGCRP to complete climate research. The issues addressed by MARS continue to be discussed because MARS sought to answer near-term policy questions and questions that naturally accompany climate change research: If the climate is changing, how will forests, agriculture, and natural areas be affected and what should we do? MARS may not have had the administrative, congressional, and program support it needed to pursue its mission a few years ago, but now MAIM-related questions are being asked with more persistence, and it might be time to consider reinstating another MARS-type program.[22] The following discussion addresses how such a program might be structured. We suggest some possible ways to incorporate adaptation into USGCRP below and in option 3-5.

A framework for developing research priorities for an adaptation research program (ARP) should be developed through a combination of an interagency committee and an external advisory panel. The interagency committee should consist of members from several scientific disciplines and the policy- and decisionmaking communities. Committee and advisory panel members should be committed to the goal of creating a management- and policy-relevant research program.

The committee and advisory panel could address the following questions:

1. **What areas** of science are important to pursue in order to support adaptation research? What existing federally supported research, which is not currently classified as global change research, could be augmented to support an adaptation-focused research program?
2. What areas of research would most effectively reduce the physical, biological, social-behavioral, and economic uncertainties faced by decisionmakers in choosing among policy options affecting global change?[23]
3. How can ARP be organized so that it is useful to public and private decisionmakers?

Answers to these questions require cooperation and coordination in the ecological and social sciences communities, coordination among the land-management agencies, and a clear delineation of the role of adaptation research in agency policy and management. As concluded by the Committee on Human Dimensions of Global Change, there is "an almost complete mismatch between the roster of Federal agencies that support research on global change and the roster of agencies with strong capabilities in social science" (35). There is a similar mismatch between the roster of Federal agencies with environmental responsibilities and the roster of agencies with strong capabilities in social science (37).

21 OTA's workshop "EOS and USGCRP: Are We Asking and Answering the Right Questions?" Washington, DC, Feb. 25-26, 1993.

21 OTA's workshop "EOS and USGCRP: Are We Asking and Answering the Right Questions?' Washington, DC, Feb. 2S-26, 1993.

22 Congress specifically asked OTA to address adaptation issues; however, if Congress chooses to instigate an adaptation program, it should also decide whether related mitigation issues should readdressed along with an adaptation program, as a separate program, or within USGCRP.

23 This question was developed in the National Acid Precipitation Assessment Program's @NM'@ 1984 annual report for Task Group I (39). Unfortunately, that task group was disbanded the next year.

The Ecological Society of America's Sustainable Biosphere Initiative (SBI) has made a start in fostering cooperation among the ecological and social sciences. SBI has clearly laid out scientific priorities in the ecological sciences. Coordination among the land-management agencies is also beginning with groups such as the Terrestrial Research Interest Group, an ad hoc coordinating committee of Federal agencies and other organizations conducting terrestrial research (see box 5-J). An adaptation program could continue to encourage such efforts.

Budget Mechanisms *for* ARP

Because the scope of any ARP would reach across agencies, a new agency or executive body, or a new office in an existing agency, could be created to house it or, as with USGCRP, a budget crosscut could be used. Because several agencies have significant expertise and infrastructure to pursue research on adaptation to global change and because of budget constraints, Congress might find it difficult to create a separate body for ARP. If an existing agency housed ARP, it could undermine the ARP mission by creating tension among agencies about interagency authority. Because budget crosscuts have worked well in the past, at least until the point when they are submitted to Congress, the use of a budget crosscut for ARP might be desirable.

FCCSET currently coordinates the budget crosscut of USGCRP and could coordinate the budget crosscut for ARP. However, because FCCSET supports science, engineering, and technology initiatives but does not initiate management- and policy-relevant deliberations within these programs, it may not be the best organization for ARP budget coordination. If an office within the White House coordinated ARP's budget, the program could more easily maintain its emphasis on policy-relevant research; however, it might be more subject to political pressure.

ARP Within USGCRP

If Congress does not wish to create anew ARP, but chooses instead to augment the existing USGCRP three points should be considered. First, the priorities of USGCRP would need to be changed. In addition to observation, understanding, and prediction, "planning' for climate change and other global changes, including adaptation, would have to be incorporated into the USGCRP goals. The seven scientific elements in the priority structure of USGCRP might need to be rewritten, with the help of advisory panels, agency personnel, and, perhaps, the National Research Council. More funds would need to be allocated to the research topics under the present Ecological Systems and Dynamics and Human Dimensions elements. Adaptation would have to be incorporated into the existing elements, or a new adaptation element would have to be added.

Second, as would be the case with a separate program for adaptation, the land-management agencies must be encouraged to unify their research programs that address ecological and human-system response to and management of global change. Congress must commit more resources to the Ecological Systems and Dynamics and Human Interactions research areas, especially within the land-management agencies. Finally, projects currently supported under USGCRP would need to be reviewed for their usefulness to adaptation research. For example, the Earth Observing System (EOS) currently concentrates on climate monitoring and ecological monitoring, primarily for the sake of determining land-atmosphere interfaces for global climate models. Could EOS be modified to provide information on processes that are important for adaptation?

EVALUATION MECHANISMS

To date, there has been no formal evaluation of the overall scope, goals, and priorities of USGCRP and of whether its activities collectively are addressing the needs of policy makers.

Several evaluation mechanisms could be used to address the dichotomy between science and policy in USGCRP, including internal and external reviews, integrated assessments, and coordinated congressional oversight. Appropriate communication links among scientific disciplines, Federal agencies, State agencies, policy makers, decisionmakers, and all levels of USGCRP are vital for its success.

■ Reviews

Most formal reviews of USGCRP elements have centered on the instruments and methods used in research about specific scientific priorities or have focused on individual projects within the program. For example, teams reviewing the EOS program have addressed specific instruments that EOS should use, and the National Academy of Sciences (NAS) has carried out reviews and midcourse evaluations of specific agency programs and projects.

Reviews should be used as a mechanism for maintaining flexibility in the program and to redirect its activities, if necessary. Reviews should: be timely and efficient; include people who do not have an immediate stake in USGCRP, but do have significant knowledge about its current structure, content, and history; be conducted periodically to reflect the nature of the questions being asked; and identify programs that can be eliminated as well as recommend new ones. Perhaps most importantly, reviews that call for a redirection in the overall program should consider that research on global change issues requires a financial and institutional commitment that transcends political and budgetary cycles. Reviews should not be used to respond to the political crisis of the day or as a mechanism to undermine effective programs with long time horizons.

■ Integrated Assessments

Reviews generally look at individual parts of a program or the program as a whole and determine how they are functioning; they do not try to integrate the program's different research results. Integrated assessments are a mechanism for synthesizing all the research relevant to an identified problem and for presenting research results in a policy context to decisionmakers (13, 42).[24] Just as important, integrated assessments help guide research and identify key assumptions, uncertainties, gaps, and areas of agreement. The Federal Government tried to incorporate an assessment process into the National Acid Precipitation Assessment Program (NAPAP) in the 1980s with only limited success (see box 3-C). A challenge for the global change research community will be to devise assessments that minimize disruption of ongoing programs but still allow for redirection of program elements in light of new discoveries, advances in technology, and changing long-term needs of policy makers.

Scientific information is critical, but not sufficient, in determining how the United States should respond to the risks of global change. If USGCRP is to be driven by social relevance as well as by scientific curiosity, its research priorities should include sociocultural factors as well as physical factors (23). Integrated assessments could help determine the importance of the problems presented by global change relative to other policy problems, outline alternative policies to respond to global change, and explain the pros and cons of various responses and implementation strategies.

For example, preliminary results of an integrated assessment computer model to prioritize policy-relevant research, by Carnegie Mellon University, suggest that: economic and ecological impacts are unambiguously the most important

24 Integrated *assessment* (also known as *comprehensive and end-to-end Assessment)* is an evolving concept. An integrated assessment of global change would generally include at least the following activities: assessments of the physical science component of a project; assessments of the potential impacts of change on the environment, human health, and the economy; assessments of the effectiveness and economic impact of possible societal responses to change; and assessments of the political feasibility of possible responses (31).

Box 3-C--Lessons from NAPAP

In 1980, Congress passed the Acid Precipitation Act (Title Vll of the Energy Security Act, P.L. 98-294) and thereby established an interagency task force to plan and oversee a 10-year National Acid Precipitation Assessment Plan (NAPAP). The National Oceanic and Atmospheric Administration, the U.S. Department of Agriculture, and the Environmental Protection Agency jointly chaired the task force, which included representatives from the Department of the Interior, the Department of Health and Human Services, the Department of Commerce, the Department of Energy, the Department of State, the National Aeronautics and Space Administration, the Council on Environmental Quality, the National Science Foundation, and the Tennessee Valley Authority along with representatives of the Argonne, Brookhaven, Oak Ridge, and Pacific Northwest National Laboratories and four Presidential appointees. The purpose of NAPAP was to increase our understanding of the causes and effects of add precipitation through research, monitoring, and assessment activities that emphasized the timely development of science for use in decisionmaking (39).

NAPAP (with an annual budget that ranged from about $17 million at the beginning of the program to just over $300 million at its end) was one of the most ambitious interagency programs ever focused on a particular problem (47). It was designed to be a major research effort that provided policy-relevant information in a timely manner. It succeeded in its research efforts, but it did not provide policy-relevant information in a timely manner. Because the nature of problems facing the country is increasingly interdisciplinary and global in scope, it is reasonable to assume that the government will mandate more programs that try to bridge the gap between science and public policy. To reap the greatest benefits from these programs, it will be necessary to incorporate the lessons of NAPAP into program structure. This box focuses on the Task Group on Assessments and Policy Analysis and the overall lessons learned from such a large, interagency program.

When founded, NAPAP consisted of 10 task groups, each with a single agency serving as the coordination contact: Natural Sources of Acid Precipitation, Human Sources of Acid Precipitation, Atmospheric Processes, Deposition Monitoring, Aquatic Effects, Terrestrial Effects, Effects on Materials and Cultural Resources, Control Technologies, Assessments and Policy Analysis, and International Activities. In 1985, the assessments and policy analysis task group was disbanded--a decision that undermined the value of the program for decisionmakers.

Congress established NAPAP in large part to determine whether acid rain was a problem. However, in the context of research NAPAP did not approach acid rain as a unified issue. Rather, it examined the subject at multidisciplinary and subdisciplinary levels with Iittle emphasis on synthesizing findings, As stated in one critique *(24):*

> The program reported findings in excruciating disciplinary detail, an approach which was not especially helpful to non-specialist decision makers. The disciplinary pluralism of NAPAP also allowed policy advocates to pick and choose among NAPAP's reported findings, emphasizing facts or uncertainties supporting a particular position and reemphasizing others. NAPAP lacked an extra-disciplinary perspective that would have allowed it to characterize acid rain as a problem, non-problem, or ' something in between,

Assessment and policy analysis research develops and uses quantitative methods to organize and communicate scientific and other information in ways that allow comparison of policy choices. These methods include decision analysis, benefit-cost analysis, risk analysis, and technology assessments. The NAPAP Task Group on Assessments and Policy Analysis attempted to begin early in the program to develop integrated assessment methodologies and to perform multiple assessments throughout the program to ensure policy relevance. A 1985 report was to include an assessment of the current damages attributed to acid deposition, an uncertainty analysis of key scientific areas, and the implications of uncertainty for policy choices. The task group also tried to develop a framework for the methodology for subsequent integrated assessments in 1987 and 1989 (25),

(Continued on next page]

Box W-lessons from NAPAP--(Continued)

However, in 1985, NAPAP's management changed and, consequently, the focus of the program changed. The assessments task group was disbanded, and responsibility for assessments was transferred to NAPAP's director of research. It was uncertain whether NAPAP would produce even one assessment: NAPAP ceased funding integrated assessment modeling because the Interagency Scientific Committee decided to spend their limited funding on other research. The new director repeatedly delayed the 1985 assessment, but it was finally released-with much controversy--in 1987. The 1987 and 1989 integrated assessments were never produced. Finally, during the last few years of the program, NAPAP produce its second integrated assessment; however, the 1990 publication of the report came too late to be of maximum use to policy makers in formulating the amendments to the Clean Air Act (47).

Because NAPAP failed to carry out the full range of assessmentis t originally planned, key components for the 1990 integrated assessment were either not pursued or were underfunded, and the assessment was incomplete (39). For example, although NAPAP was initially supposed to evaluate the economic effects of add deposition on crops, forests, fisheries, and recreational and aesthetic resources and to determine the implications of alternative policies, funds were significantly reduced for research in these areas (47).

The Oversight Review Board (ORB) of NAPAP, in its 1981 report to the Joint Chairs council of the Interagency Task Force on Acidic Deposition, strongly emphasized that an assessment function be given primacy throughout an interagency program (39). ORB's keyrecommendation on lessons learned about the interface between science and policy was to give assessment priority over research (24) because "science and research findings *per se* have little to offer directly to the public policy process, [and] their usefulness depends on assessment, defined as the interpretation of findings relevant to decisions" (39). ORB also outlined eight other suggestions that any program with such a close interface between science and policy should follow:

1. Match institutional remedies to problems.
2. Obtain and maintain political commitment.
3. Take steps to ensure continuity.
4. Configure organization and authority to match responsibility.
5. Give assessment primacy.
6. Provide for independent external programmatic oversight.
7. Understand the role of science and how to use it.
8. Take special care with communication.
9. Prepare early for ending the program.

The insights gained from the experiences of NAPAP were not considered when designing the U.S. Global Change Research Program (USGCRP)-a much larger program on both a temporal and spatial scale than NAPAP. Some argue that USGCRP is following the same path as NAPAP--good research will come from USGCRP, but the results will not be used to inform policy, and decisions concerning global change will be made with little more knowledge than is available today (42). The logical questions to ask are: Why didn't Congress use the experiences of NAPAP in formulating legislation for USGCRP, and how should incorporation of lessons from NAPAP be integrated into USGCRP and future Interagency programs?

SOURCE: Office of Technology Assessment, 1993.

sources of uncertainty **and** that reducing the uncertainty is more important than resolving the differences among climate models; the priority placed on research in different fields will vary according to the policy objectives chosen and the time horizon; although they must not be ignored, uncertainties about climate variables appear, in many cases, to be less important than certain social, economic, and ecological factors; and models that measure all impacts in monetary terms are unlikely to be able to explore many of the most important aspects of the climate problem (15).

Regardless of the scope of an integrated assessment, its primary functions should be: to identify key questions to be answered, to survey the state of current scientific judgments about what we know and do not know about global change and its impacts, to identify and prioritize what the key uncertainties are in relation to policy needs, to list key assumptions and judgments, to identify where new research is needed to aid the policy process most effectively, including research on key uncertainties in understanding the climate system and fostering mitigation and adaptation research, and to establish the requirements for peer and public review (24, 42).

Assessments need not be conducted sequentially (e.g., results of earth science research or economic research need not be complete before an assessment can begin), but should begin at the beginning of a program and continue throughout the life of the program (l). The ideal assessment would pay particular attention to bridging gaps and maintaining essential links among various research projects and disciplines and would determine the value of new information.

The Massachusetts Institute of Technology, Carnegie Mellon University, the Electric Power Research Institute, and Battelle Pacific Northwest Laboratory have programs for developing computer models for integrated assessments. For example, the Battelle Pacific Northwest Laboratory is developing an Integrated Climate Change Assessment Model (ICCAM)[25] that will incorporate information from models on human activities, atmospheric composition, climate and sea level, and terrestrial ecosystems (17). ICCAM is intended to be an integrated collection of these models in a reduced, or simplified, form, with the goal of giving practical answers to practical questions. The models are limited by the complexity and uncertainty of each system, and some fear that the results from these integrated assessments could be difficult to understand. However, these models can at least help to structure thought, direct inquiries, identify which uncertainties are important and which are not, and suggest courses of action (40).

Assessments could be performed by independent, nongovernment committees, Federal interagency task forces consisting of agency personnel who are participating in the program, a mix of the two groups, or by the National Academy of Sciences (42). Nongovemment committees would offer the fresh perspective of independent evaluators who are less weighed down by political agendas; however, they might have little control over the agencies they are trying to influence. Interagency committees would have the advantage of using Government researchers who are well-informed about the program and who could not easily ignore assessment findings.

To date, integrated assessments have received little administrative support and almost no funding from any ongoing program. Some agency personnel have expressed interest in integrated assessments, but few have committed any resources to it (EPA and DOE have funded some assessment research). The little funding that integrated assessments have received has come largely from NSF and the Electric Power Research Institute. A small percentage of the total USGCRP budget—perhaps 1 to 5 percent--could be set aside for integrated assessment (15, 50). The Carnegie Commission also recommends that a larger percentage of environmental research and development dollars go toward assessment and policy research (4).

25 Battelle Pacific Northwest Laboratory is working in conjunction with the University Corporation for Atmospheric Research, the Electric Power Research Institute, the U.S. Department of Energy, and the Environmental Protection Agency.

■ Congressional Oversight

Congress has held several hearings on global climate change that have focused predominantly on what we know, what we do not know, the accuracy of current data, reconciling the existence of conflicting data, the implication of climate change for natural resources and the economy, and the potential costs of actions designed to mitigate climate change. However, these hearings have not successfully addressed USGCRP as a program. Some hearings have focused on the current research of program participants, which is a first step in determining the necessity of the research, but few have focused on whether USGCRP research was supplying information needed to develop policy responses to global change. The direction of the program and its emphasis on the frost two science elements have not been altered.

In addition, the different committees with jurisdiction over USGCRP have not been equally active in their oversight activities. As a result, certain portions of the program are regularly reviewed while others are never reviewed.

New approaches to traditional authorization and appropriation procedures for large interagency programs such as the USGCRP need to be considered. The current authorization and appropriation process guarantees that USGCRP will be examined by Congress only in pieces (38). An annual, ad hoc appropriation subcommittee might be created to specifically address the USGCRP budget as a whole. This committee should consist of members from appropriation subcommittees with jurisdiction over elements of USGCRP (see table 3-2).

For congressional oversight to be effective in influencing USGCRP, a long-term systematic approach to communication and oversight must be developed. Congressional feedback, expectations, and prospective actions must be communicated quickly to the program. Oversight should be extended to include regular meetings among policy makers who have jurisdiction over USGCRP and USGCRP participants; an interdisciplinary, multiagency group working with USGCRP; and outside reviewers. Results from these meetings should be freely and widely disseminated. Oversight hearings should be coordinated with all committees who have jurisdiction over USGCRP (see table 3-l).

POLICY OPTIONS: AUGMENTING THE FEDERAL RESEARCH EFFORT ON GLOBAL CHANGE

To policy makers, climate change does not become a problem the moment that the change in the Earth's mean average temperature becomes statistically significant. For them, it becomes a problem when a community feels the pinch of an unwanted event-drought or flood or decline of timberland, for example. Knowing how best to ameliorate or cope with any costs that climate change might induce is important to policy makers. Knowing how mitigation efforts to reduce greenhouse gases will affect our ability to adapt is important. Knowing what information is knowable and unknowable over various time scales is important to policy makers. This kind of information does not automatically emerge from a basic research program. To be useful to the governing bodies of the world, the science facts gained by USGCRP must somehow be translated into potential costs or benefits incurred by climate change and must guide strategies to prepare for or react to change. Currently, there is no formal mechanism in USGCRP for making the link between policy and science.

Given the complicated and long-term nature of climate change, the research needed to understand it, and the shorter-term needs of policy makers, a research program for global change should ideally:

- identify the key science and policy questions for the near term and the long term;
- orchestrate a research program that involves the physical, biological, and social scientists;

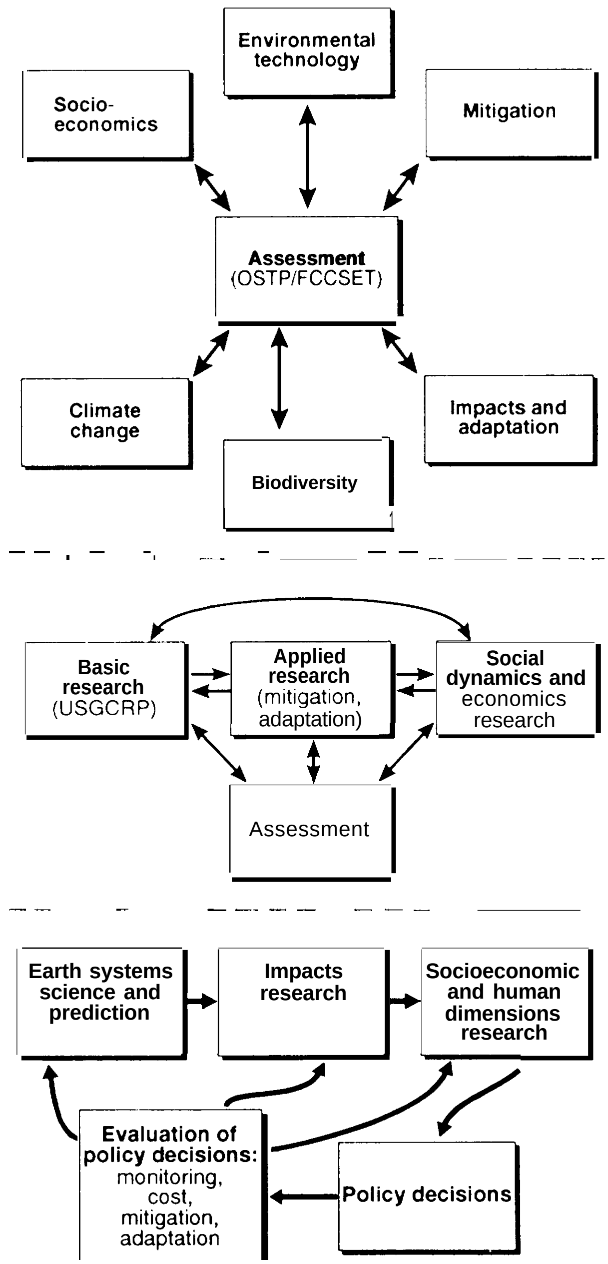
- integrate the research results across disciplines (i.e., assess the state of understanding) periodically; and
- communicate results back to the researchers and policy makers effectively.

Identifying the outcomes that matter to policy makers should be the first step in refining global change research programs, with scientists helping the policy makers to ask pertinent questions (14). Next, scientific priorities should be compared with the policy questions. Where there are serious mismatches between scientific and political priorities, programs should be reevaluated-not to direct a basic science agenda, but to ensure that key information needed for policy decisions from many disciplines is available alongside the fundamental chemistry and modeling. The particular disciplines, research methods, and instruments that would be used to gather and analyze data should flow from these priorities and should be science-driven. Ideally, information needs of decisionmakers will influence questions asked by scientific researchers, and vice-versa. For example, the communication between scientists and policy makers may cause a change in key policy questions, which in turn may redirect the research program; "policy makers need to understand the limitations of what science can determine, and scientists must understand what the policy community really needs" (42). This has proved difficult in past research efforts, such as NAPAP's (See box 3-C).

The following policy options generally fall under three categories:

- Effectively broaden USGCRP by incorporating results of Federal research relevant to but not currently under its purview. USGCRP as currently constructed and implemented cannot do this. It could require congressional or executive branch codification. There are several policy options directed both at broadening USGCRP and at ensuring that USGCRP and other programs relevant to global change are connected (the diagrams in fig. **3-8** show some possible organizational schemes for building in some of the missing components). The National

Figure 3-8-Alternative Organizational Schemes for Global Change Research



SOURCE: Office of Technology Assessment, 1993.

Research Council has recommended the creation of a National Environmental Council in the Executive Office of the President (37), and the National Commission on the Environment (NCE) recommended the development of a National Environmental Strategy (34); either or both of these could complement the options described below.

- Increase funding or redirect funding to areas where research is inadequate. A modest redirection of 1 to 5 percent of current funding ($15 to $70 million) could begin filling in the large gaps between the current climate change program and a policy-relevant global change program (15, 50). Because the bulk of this OTA report focuses on natural-resource-based systems and the Nation's potential to adapt to climate change, we discuss coordinating existing ecosystem research and initiating new efforts that are critical to planning for and/or managing natural resources under climate change. However, building strong socioeconomic components of USGCRP is equally important.
- Make the program more relevant to policy making by incorporating an assessment function. Assessment and regular reevaluation of USGCRP could be instrumental in identifying the current information base on climate change, gaps in knowledge, and short- and long-term policy questions.

Effectively Broaden USGCRP

As currently structured, USGCRP is a collection of programs from several agencies with no central management. Although research should remain decentralized, coordination should be centralized and top-down. The Subcommittee on Global Change Research under the Committee on Earth and Environmental Sciences is currently responsible for coordinating activities under the Federal Coordinating Council for Science, Engineering, and Technology. FCCSET acts largely as a fulcrum for coordination, but agency participation in FCCSET projects is voluntary, and FCCSET has no authority over how participating agencies spend their funds. A previous OTA report (48) looked broadly at the health of U.S. research and development and concluded:

> In the Executive Branch, Congress should insist, at a minimum, on iterative planning that results in: a) making tradeoffs among research goals; and b) applying (after scientific merit and program relevance) other criteria to research decisionmaking that reflects plarnning for the future. . . OSTP [Office of Science and Technology Policy] could initiate broader priority-setting.

Option 3-1: Amend *the Science Policy Act of 1976 (PL. 94-282), which established the Office of Science and Technology Policy and the Federal Coordinating Council on Science, Engineering, and Technology, to strengthen the ability of these offices to coordinate science and ecosystem management across agencies.* OSTP was established to "define coherent approaches for applying science and technology to critical and emerging national and international problems and for promoting coordination of the scientific and technological responsibilities and programs of the Federal departments and agencies in the resolution of such problems, ' and FCCSET was established to "provide more effective planning and administration of Federal scientific, engineering, and technological programs" (P.L. 94-282). These offices have the authority to develop and implement coherent, Government-wide science policy and have been the mechanism for coordinating several multiagency programs. However, OSTP has not always been an active or influential player in the executive branch, and FCCSET lacks the authority to set priorities, direct policy, and fully participate in the budget process (2, 21). The directions for environmental research must be set—and responsibilities among various Federal agencies must be coordinated-at the executive level because environmental research is of the highest national importance.

About 20 Federal agencies have major responsibilities related to the environment. In all instances (except for EPA), concern for the environment is not the primary role of the agency conducting the environmental research (37). For example, DOE supports much environmental research, but the department's primary responsibility is energy, not the environment.

OSTP could be given budgetary authority, perhaps in conjunction with the Office of Management and Budget, to guide agency programs that contribute to science and technology. This could mean reinstating "fencing," or requiring agencies to commit funds to USGCRP projects (see footnote 12). These funds could not then be redirected to meet OMB targets for other areas within each agency.

A further step would be to create a National Science and Technology Council to replace FCCSET as proposed by Vice President Gore in his National Performance Review (21). Under this plan, agencies would clear their budgets with the science council as well as with OMB.

Option 3-2: *Establish a committee within FCCSET to standardize the criteria for classifying focused and contributing research to USGCRP and to classify all government research accordingly.* Much research that could qualify as ''contributing' to USGCRP may be ongoing under another title (such as ''Environmental Biology;' see option 3-6 below). Likewise, more "focused work" might occur in the agencies if the USGCRP scope is broadened. A defined set of criteria for classifying research would be of great value in identifying Federal research that is truly pertinent to the global change problem and in identifying critical gaps in research.

Option 3-3: *Reassess program priorities. Reassess the* order of priority given to the seven science elements. Although the current structure is producing good science, research results will not be sufficient to provide the information necessary to answer policy questions concerning the impacts of climate change on the Nation's resources. To answer these questions, more emphasis needs to be directed toward the science elements that address the ecological, socio economic, adaptation, mitigation, and human aspects of global change. Some of this can be done easily within the current construct of USGCRP; some may require additional programs outside the USGCRP research structure.

Option 3-4: *Make research on the human dimensions of global change a primary element of the program.* A human-dimensions program would look at the interface between human actions and the natural environment. Humans alter the environment through population growth, economic growth, technological change, political and economic institutions, and attitudes and beliefs. Human response to a changing environment will depend on individual perceptions, markets, sociocultural systems, organized responses at a subnational level, national policies, international cooperation, and global social change (35). These elements of a human-environment interface will directly influence adaptation responses to climate change.

Option 3-5: *Create an adaptation and mitigation research program (ARP) either within USGCRP or separate but parallel to it.* This program should either have the authority to influence project selection throughout USGCRP or feed into a formal assessment process that influences program direction. Congress must decide whether an ARP should function as a program separate from, but parallel, to USGCRP or whether ARP should operate within USGCRP. If ARP is created as a separate program, it should have formal ties to USGCRP. If USGCRP subsumes adaptation, the USGCRP mission would have to change to make adaptation equal in importance to the other three activity streams.

The mission of such a program must explicitly state its management and policy orientation. ARP's mission might be:

> . . .to pursue research that will support public and private decisionmaking on issues related to global change if climate change occurs. At a minimum,

research will include studies of the public and private management of natural and managed systems and of how to develop strategies to adapt to the effects of climate change. Annually, the program will assess the state-of-the-science, develop Government policy and management options for responding to the potential for global change (including programs that supply information to private decisionmakers), and incorporate these findings into new research directions. The assessment, policy options, and new directions for research will be reported to Congress in an annual report presented along with the President's Budget Request,

The program must include a formal mechanism for bridging the gap between science and policy; specifically, integrated assessments need to be at the center of any ARP structure. Congress should consider mandating this in any enabling legislation in order to ensure that assessments are given top priority.

Congress should consider several "rules of thumb" in structuring the program:

- Management agencies should act as the lead agencies.
- Goals for research must have problem-oriented task descriptions and milestones that are specific and easily measurable.
- Congress should consider retaining the "power of advice and consent in the appointments of the director and assistant directors of the program.

Other mechanisms for ensuring policy relevance could include requiring the program to make periodic reports to Congress, and giving Congress oversight and investigation authority.

If Congress chose to augment USGCRP, it must recognize that the program has little ability at present to target its programs to help public and private decisionmaking. Given the structure of USGCRP, management- and policy-relevant research would be hard to initiate because the process of setting priorities in USGCRP is dominated by key agency personnel in conjunction with members of the national and international scientific community.

Incorporate More Ecosystem Research and Natural Resource Planning Into USGCRP

Although an estimated $900 to $943 million is spent on what can be considered research in environmental life sciences (22) or environmental biology,[26] there is currently very little ecological research directed specifically at protecting natural areas under climate change and helping land managers modify management strategies to respond to climate change.[27] Of the $943 million that FCCSET estimates is spent on environmental biology, only 11 percent was also reported as USGCRP program money.[28] A former working group under FCCSET found that in 1992, only $8 million was spent on research focused on adaptation.[29] This number represents less than 0.8 percent of the USGCRP budget and less than 0.9 percent of the amount spent on environmental biology research. A review of ecological experiments from 1980 to 1987 found that 50 percent of all studies were done on very small scales--on plots less than 3 feet in diameter; only 7 percent lasted longer than 5 years. Large-scale and long-term experiments are essential to respond to

26 J. Gosz, Executive Secretary, subcommittee on Environmental Biology, Committee on Life sciences and Health, Federal Coordinating Council for Science, Engineering, and Technology, personal communication, Sept. 14, 1993.

27 FCCSET defines *environmental biology* as all areas of biology dealing with the study of organisms and their interactions with their biotic and abiotic environment (J. Gosz, personal communication, Sept. 14, 1993). Gramp et. al. (22) defiie *environmental life sciences as processes* and interactions of living resources such as environmental biology, including ecology, forestry, biology, and marine biology.

28 Gosz, op. cit., footnote 26.

29 The Working Group on Mitigation and Adaptation Strategies (disbanded in 1992) of the Committee on Earth and Environmental Sciences of FCCSET identified Federal research that focuses on or contributes to adaptation to global change (6).

the challenges of global research (37). Yet, research on large-scale ecosystem management, structure, and function is necessary to protect natural areas in the future, and it is not clear that it is occurring under the auspices of ' ● environmental biology' or USGCRP.

USGCRP as currently designed will not provide either the practical technologies that might allow us to be more prepared for climate change or the ecological information that would be helpful in providing policy guidance and adaptation options for natural systems.

Option 3-6: *Conduct a review of ecological research within USGCRP and across Federal agencies, evaluate how much long-term ecosystem-level research relevant to climate change, biodiversity, and other long-term problems is under way; and identify important gaps in ecological research.* A review of all research on ''natural resources' has not yet been conducted across the Federal agencies. Existing analyses suggest a great deal of money is spent on research relevant to the environment, but how much is useful to understanding long-term ecological problems (such as biodiversity and climate change) is not known. There is currently no mechanism for consolidating results from disparate research efforts into ''general patterns and principles that advance the science and are useful. for environmental decisionmaking. Without such synthesis studies, it will be impossible for ecology to become the predictive science required by current and future environmental problems' (32).

In volume 2, chapter 5, of this report, we highlight key gaps in our understanding of ecosystems, such as: past climate changes and corresponding species responses, restoration and translocation ecology, the effectiveness of corridors and buffer zones, the development of ecological models, and the effect of elevated CO_2 on assemblages of plants and animals.

Basic research in these areas is needed now to determine how species might respond to climate change and how best to provide for their protection in the future. Agencies could attempt to redirect existing funds within USGCRP or procure new funds for addressing these basic ecological research needs under the Ecological Systems and Dynamics research area. Alternatively, NSF, whose mission is to support basic scientific research, could take the lead in supporting these research areas outside the auspices of USGCRP. The new National Biological Survey (see ch. 1 and vol. 2, ch. 5) could also be an appropriate vehicle to use in addressing some of the research that directly relates to land-management issues.

An effort to characterize and synthesize ongoing research could help bridge the gap between basic research and natural resource planning. Such a review could be conducted by OSTP, NAS, or an independent commission.

Option 3-7: *Make research on monitoring and managing natural resources a key component of a broadened global change research program. One* of the most prudent approaches to natural area conservation under climate change is more coordinated management on the ecosystem or regional scale. This approach would also help address threats to biodiversity and maximize possibilities for species survival under climate change. The land-management agencies should receive increased funding--or existing funds should be redirected-for research that would directly address concerns of managing natural resources under climate change. In particular, as the National Research Council recommends (37), "environmental research should advance the social goals of *protecting the* environment for present and future generations, *restoring* damaged environments so that they are productive once more, and *managing our* natural, economic, cultural, and human resources in ways that encourage the sustainable use of the environment.

Inventory and monitoring programs are usually the last to get funds and the first to be cut in a budget crisis (36, 55); existing institutions are poorly designed to support and strengthen them (37). Many monitoring programs that have been established in protected natural areas have been discontinued because of personnel changes, policy alterations, or budget cuts (55).[30] Baseline information is needed on the status and trends of vegetation cover, plant distributions, animal distributions, soils, and water resources to detect and monitor climate-induced changes. All Federal agencies conduct some type of inventory as a matter of policy, but these efforts vary widely in completeness and quality, are not consistently implemented and funded, and are not coordinated at the national or even agency level.

A concerted effort to connect, in a timely manner, the information contained in inventories to the resource-management and land-use-planning process is vital. If these connections are not adequately addressed, the gap between research and management could increase, which would be detrimental to DOI's new National Biological Survey.

Incorporate Assessment and Oversight

Option 3-8: *Amend the U.S. Global Change Research Act of 1990 (P.L. 101-606) to require periodic integrated assessment reports to be presented to Congress and specify key participants in the assessment process. If* such a program is incorporated into USGCRP, it should be positioned above the agency level. However, because all of the elements necessary for an integrated assessment are not found in USGCRP, an assessment program would have to incorporate information from outside the program and include research that is not formally contained within USGCRP but that contributes to it. An assessment program should fund external and internal assessment efforts. Because integrated assessments that use computer models to knit together all aspects pertinent to global change are not well-developed, they should be used only as a guide to steer program elements. To ensure policy relevance, an assessment program must be given the authority to influence program priorities and project selection. Assessment teams must be interdisciplinary. Documenting the state of scientific knowledge is listed as the primary function of the newly created Assessment Working Group; however, the results of such a survey are highly dependent on the questions being asked-what is regarded as unknown or uncertain depends on what one wants to know and the perspective and background of the person or team carrying out the assessment (24). To ensure commitment and accountability to the assessment process, the director of an assessment program could be appointed with the advice and consent of Congress.

Option 3-9: *Create innovative congressional involvement in USGCRP.* USGCRP does not function as an individual agency, and Congress cannot expect to interact with the program in the same manner it does with agencies. Congress needs to create a forum where USGCRP can be addressed as a whole before being broken down into individual components that fit neatly into authorization and appropriation jurisdictions. For example, the Environmental and Energy Study Institute could conduct an annual seminar for its congressional members on the USGCRP budget, or Congress could establish an ad hoc appropriation committee consisting of members from each committee and appropriations subcommittee with jurisdiction over USGCRP to consider the program's budget as a whole.

Congress should conduct oversight of the program as a whole. Because USGCRP is an interagency program, it cannot be evaluated effectively by Congress on an agency-by-agency basis or through the activities of individual committees working independently. Committees with jurisdiction over USGCRP should coordinate oversight of the program.

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[30] For example, in FY 1993, the Bureau of Land Management (BLM) eliminated 6 of its 16 acid rain stations to release about $30,000 fOr other BLM activities. Several of the six stations had been in operation for 10 years and had been maintaining data seta to monitor the health of forests and the effects of acid rain. Continuation of this long-term record was lost as a result of these cuts.

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Wetlands 4

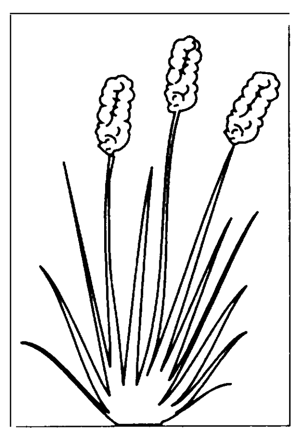
Status
- Despite "no-net-loss" policy, wetland destruction and degradation continue.
- No single statute directly protects wetlands.

Climate Change Problem
- Climate change is likely to accelerate wetland loss.

What Is Most Vulnerable?
- Coastal wetlands (sea level rise).
- Western depressional wetlands (midcontinent warming and drying).
- Western riparian wetlands (midcontinent warming and drying).
- Tundra (largest warming at high latitudes).

Impediments
- Absence of clearly stated national policy for protecting wetlands.
- Different authorities and goals scattered across numerous Federal, State agencies.
- Federal policies have often failed to discourage, and have sometimes encouraged, wetland destruction.
- Inadequate criteria for decisionmaking; lack of an overarching priority plan for protection, restoration, and acquisition.
- No coordinated effort to monitor and evaluate wetlands.

Types of Responses
- Protect existing wetlands.
- Restore degraded or converted wetlands.
- Facilitate migration.
- Improve coordinated management and monitoring.



OVERVIEW

Wetlands are extremely complex and sensitive ecological systems that cover roughly 5 percent of the lower 48 States, but even today, the value of these systems is not always understood or appreciated.

Concern about steadily increasing losses of wetlands led the Federal Government to embrace a policy goal of no net loss of wetlands in **1989.** The policy specifies that destruction of wetlands should be offset by an equivalent restoration or creation of wetlands (see box 4-A). Efforts to move toward that goal have led to major controversies over how to define wetlands, the criteria and procedures necessary for mitigation, and the extent of Government involvement in regulating

Box 4-A–Wetland Mitigation and Restoration: Maintaining Wetland Functions and Values

During the 1950s to1970s,458,000 acres (183,200 hectares)[1] of wetlands were being lost each year, mainly to agriculture and urban and suburban development. That **pace has** been slowed to 100,000 to 200,000 acres per year, primarily due to Iegislative efforts. Wetlands serve many functions that are difficult to quantify in eoonomic terms; they are critical for storm-water retention, water quality control, and provision of wildlife habitat. Developing methods of restoring lost or degraded wetlands would help to alleviate problems resulting from their destruction, help achieve the Nation's goal of no net Ioss of wetlands in the short term, and increase the quantity and quality of wetlands in the long term.

Wetland mitigation is simplyalleviating any or all detrimental effectsthat may arise from harming a wetland. Mitigation includes enhancement, creation, and restoration; it may be done to formally complywith Section 404 of the Clean Water Act or for other reasons. Mitigation may involve the in-kind restoration or creation of **wetlands-in another** location--or the enhancement of services and functions of the wetland being harmed in place.Enhancement involves increasing one or more functions or values of an existing wetland (e.g., flood control, water quality improvement, and habitat provision). Creation refers to the complete conversion of an upland area into a wetland; it is the most difficult of the three and, so far, the least successful.

Wetland restoration involves the reestablishment of aquatic functions and related physical, chemical, and biological characteristics that were Iost from a wetland. There are basically three categories of restoration techniques: 1) reestablishing and/or managing wetland hydrology, 2) eliminating or controlling wetland contaminants, and 3) reestablishing and/or managing the native plants. Sound plannig, project management and broad-based scientific knowledge regarding wetland processes are all critical elements in achieving a successful restoration. Wetland restoration is not easy because wetlands are complex ecosystems that Involve interactions between **a** multitude of species, and many of these relationships are not fully understood.

Wetland restoration is also a controversial practice for several reasons. The success of restoration techniques is not dear, mostly because there has been little investment in monitoring and evaluation (13). In addition, the measurement of success is elusive and complex. Success varies according to the value **and function** the project aims to restore. These functions range from providing wildlife habitat to flood control to water filtration. Determining success on the basis of these functions requires long-term evaluation as systems evolve **and** mature; some wetland system will respond more quickly and more positively to restoration than others. There are few documented, definitively successful cases; however, coastal marsh-restoration projects are generally more successful than restoration of inland freshwater marsh systems, mostly because coastal hydrology is better understood and, thus, more easily restored (13). Projects that have occurred outside the regulatory process have been more successful.[2] Factors such as unclear project goals, lack of monitoring, and an inadequate understanding of the wetland ecosystem have contributed to restoration failures,

1To convert acres to hectares, multiply by *0.405.*

2 *K.L. Erwin, Consulting Ecologist,*Inc., personal **communication,** July *1993.*

Several Federal agencies are attempting to incorporate wetland-mitigation activities into their land-management plans. For the most part, these aim to retard wetland loss while doing little in the way of actual restoration (7). These efforts are heralded by the Army Corps of Engineers (the Corps), the Environmental Protection Agency (EPA), the Fish and Wildlife Service (FWS), and the National Marine Fisheries service (NMFS). The Corps is mainly concerned with replacing or providing substitutes for wetlands that have been reduced or subject to the adverse effects of water-resource development projects (7). EPA follows the Corps' criteria for evaluating discharges that have an adverse impact on surface- and groundwater systems, but has yet to issue any specific guidance on mitigation (7). FWS has developed a comprehensive mitigation policy that focuses on habitat value, and mandates that the degree of mitigation requested correspond to the value and scarcity of the habitat at risk. More importantly, the policy recommends that altering highly valued wetlands be avoided. NMFS has taken a proactive approach by participating in the early planning stages of wetland-restoration projects. In this way, the agency can offer guidance on identifying alternatives to wetland destruction, decreasing conflict anticipating problems, and minimizing potentially adverse effects on living marine resources and habitat.

In response to vast wetland losses, a *mitigation banking* program was developed as a mechanism for compensating unavoidable habitat losses associated with development activities (e.g., construction of roads and buildings) and administered primarily under the Clean Water Act (CWA; P.L. 92-500). The program includes the participation of agencies, nonprofit organizations, and private entities and involves off-site creation, restoration, and/or enhancement of wetlands. It is carried out by the private sector through the Section 404 permitting process and other similar State and local wetland regulations. The National Environmental Policy Act (NEPA; P.L. 91-1907) and the wetlands Executive Order (1 1990) encourage the exploration of alternatives to actions that would destroy wetlands. Mitigation, as an alternative, must address impacts and cannot be used simply to offset the acreage of wetland losses. Successful mitigation includes "replacing the loss of aquatic resource values by creating, restoring, and enhancing similar functions and values" (33 CFR, App. A, 334, July 1, 1992). This does not necessarily imply a one-to-one ratio of destroyed to mitigated acreage. Problems with enforcement, implementation, and monitoring of wetland mitigation have raised questions about the success of mitigation programs.

Restoration goals are bound to vary from region to region. For example, in urban areas, flood control and water filtering are highly valued functions of wetlands. Restoration of these functions does not require a fully vegetated wetland that supports fish and wildlife; the most important part of restoring these functions maybe simply to dear obstacles from the site and plant enough vegetation to anchor the soil. In other sites, including those in areas important for wildlife but where considerable habitat has been destroyed, a more complete restoration project to rehabilitate a broader range of functions maybe preferred. In some cases, technologies can be used to establish an artificial wetland for tertiary wastewater treatment. This application requires greater manipulation of the land and the installation of piping systems to regulate flow across the manually planted areas. Artificial wetlands are being successfully used to treat agricultural and urban wastewater in smaller communities across the country. As this technology is expanded, it may be more widely used as a low-cost, low-maintenance alternative to traditional wastewater treatment applications.

Using restoration as a way to offset loss of healthy wetland systems by creating new wetlands in another location often results in a trade to lower function and value. In some cases, though, a trade may make good sense. For example, allowing development on a small, isolated wetland in a highly urbanized area in exchange for protecting a larger tract that is in a migratory bird flyway could be beneficial in the long term. Several such projects are under way on the California and Oregon coasts, where migratory waterfowl habitat has been lost at rates that surpass those in the rest of the country.

In the San Francisco Bay area, for example, hundreds of acres of tidal marshland were restored after having been diked off and converted for cattle grazing, mostly during the 1930s. The original salt marsh was dominated

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Box 4-A-Wetland Restoration and Mitigation: Maintaining Wetland Functions and Values--(Continued)

by pickerel weed, which moved into "seasonal wetlands" toward upland areas, which are inundated by precipitation during the fall and winter months but dry out in the spring and summer. The restoration was a joint project between a private entity and the State. The private group was interested in developing the upland areas and, in exchange, created a restoration design that aimed to reestablish the original water-flow patterns in the degraded marsh, which allow vegetation to prosper; the design assumed that vegetation would colonize the area gradually, so an extensive planting program would not be needed. Sand and silt were excavated to create basins within the marsh, surrounded by a shelf that would support vegetation, and the dike was breached, allowing the bay waters to flow inland and reclaim the dormant marshland. Natural sedimentation processes could then occur, helping to resters the proper substrate conditions that would eventually support new tidal-marsh vegetation. The restoration is continuing naturally and, with monitoring, the wetland will probablybefunctional in a few years. In other cases, plants might have to be manually reestablished, and in inland or riparian-wetland situations, restoring the hydrology would be much more difficult. In all cases, however, it is important to perform a complete environmental assessment of the site before any fieldwork begins.

Wetlands are extremely complex systems that include a multitude of species of microbes, plants, birds, and other wildlife. Their interactions are highly developed; it has taken hundreds or thousands of years for these systems to achieve their level of ecological and functional diversity. Restoring destroyed wetlands or improving damaged ones requires not only a clear understanding of this dynamic and complex ecosystem, but also a well-ordered plan that attempts to account for difficulties that may arise during the restoration. A comprehensive monitoring program is necessary to track the restoration of a wetland's functions. Additional research is needed to improve restoration technology to help prevent the continued loss of the Nation's wetlands and to begin to regain some of what has already been lost.

SOURCES: K.L. Erwin, An Evaluation of Wetland Mitigation in the South Florida Water Management District (1990), Volume 1, report prepared for the South FloridaWater Management District, July 1991; K.L. Erwin, Consulting Ecologist, Inc., personal communication,July 1993,Interagancy Committee on Wetlands Restoration and Creation, A National Program for Wetlands Restoration and Creation, report to the Policy Coordinating Group Interagency Task Force on Wetlands, August 1992;J.AKusler and M.E. Kentula, Wetland Creation and Restoration: The Status of the Science (Washington, DC: Island Press, 1990); L. Roberts, "Wetland Trading is a Loser's Game, Say Ecologists," Science, vol. 260, June 25, 1993, pp. 1890-92; D. Salveson, Wetlands: Mitigating and Regulating Development Impacts (Washington, DC: The Urban Land Institute, 1990).

the use of private land where most wetlands exist (see box 4-B). As the debate continues on how to achieve the no-net-loss goal, the possibility of climate change, which may make halting the loss of wetlands even more difficult, looms on the horizon.

Four types of wetlands appear to be particularly vulnerable to climate change: coastal wetlands, depressional wetlands in arid or semiarid regions, riparian wetlands in the arid West and Southwest, and tundra wetlands. Coastal wetlands may be drowned by rising sea or altered by changing salinity. Arise of about 1.5 feet (about 0.5 meter)[1] could inundate more than 30 percent of coastal wetlands. Depressional wetlands maybe affected by lowered water levels-the likely result of higher temperatures, increased evaporation, and decreased precipitation in already dry areas. Drier conditions in the West also may threaten riparian wetlands that rely on water from rivers and streams. Tundra areas may shrink as increased temperatures allow the permafrost to thaw and drain.

Climate change may cause loss of wetlands, even as the need for wetlands becomes greater under climate change. For example, healthy

[1] To convert feet to meters, multiply by 0.305.

Box 4-B-How Wet Is a Wetland?: The Debate Over Which Wetlands to Regulate

The regulatory system has tied itself into knots attempting to meet the policy goal of "no net loss'' of wetlands. The simple-sounding goal is made complicated by the lack of an accepted definition for "wetland." Other issues have also yet to be reconciled, such as: How wet must a wetland be--and how often must it be wet? How can boundaries be drawn around it to distinguish a wetland that is covered by Federal regulatory programs (a jurisdictional wetland)from an adjacent area that is not? TheAdministration's efforts to clarify these issues set off a firestorm of controversy surrounding not only fundamental issues in wetland science, but also the relationships among science, politics, and policy.

In August 1991, a new policy program to meet the no-net-loss goal was announced. As part of that program the Environmental Protection Agency (EPA), the Army Corps of Engineers (the Corps), the Soil Conservation Service (SCS), and the Fish and Midlife Service (FWS) published in the *Federal Register* proposed new delineation manual, which was to be used for decisions about wetlands across all agencies. The manual stated that to be considered a wetland, an area must be flooded for 15 consecutive days, or saturated to the surfacefor 21 consecutive days, sometime during the growing season. This definition would exclude from regulation wetlands that are only sporadically inundated (e.g., in floodplains and prairie areas) and that may be dry for the greater part of the year. The manual imposed a high burden of proof, requiring that certain vegetation types, soils, and hydrology (water flow) be documented according to detailed rules of evidence.

The proposed manual set off an immediate uproar. Critics in the scientific and environmental communities claimed that there was no defensible scientific rationale for stating that wetlands must be flooded or saturated for so many days in a row, that the proposal would exclude up to half of the areas now regulated as wetlands, and that the manual--which was supposed to streamline the regulatory process--was actually more difficult, time-consuming, and expensive to use than the manual then in use. Supporters of the proposal, including farmers' and developers' organizations, favored the exclusion of "drier" wetlands, contending that the wetter ones were more important to protect. They argued that existing regulations were inconsistent, placed too great a burden on private landowners, and interfered in property rights, producing numerous horror stories of permits gone awryand causing untoward delays. By January 1992, EPA received more than 60,000 comments on the proposed manual. To date, no further revisions have been issued. in the interim, Congress requested a National Academy of Sciences study of wetlands delineation, and the agencies have fallen back on one or another version of manuals used in the past to determine what a wetland is.

Although particularly heated in 1991 and*1992,* the debate over what to regulate and how to recognize it dates back to 1972, when the Clean Water Act (P.L. 92-500) was passed. The act promoted protection of the Nation's water quality and established a permit program to regulate the dredging and filling of U.S. waters. The permit process was to be overseen by the Corps in its capacity for managing navigable waters. Four other Federal agencies-EPA, FWS, the National Marine Fisheries Service (NMFS), and SCS--along with State agencies ***were*** also allowed to review and comment on permit applications, but of the four, only EPA could veto a permit. When the Corps published regulations to implement the act it interpreted the mandate narrowly as including only traditionally navigable waters. Environmental groups sued, and a court order forced the Corps to issue new regulations in 1977 that covered a broad range of headwaters and wetlands. After considering 22 different definitions of wetlands, the Corps settled on the definition, also adopted by EPA, that is still used today in its regulatory decisions: "areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation adapted for life in saturated conditions" (33 CFR328.6(6), 1991). Somewhat different definitions are used by other-s, such as FWS or the U.S. Department of Agriculture (USDA), whose purview includes wetlands.

Broad application of the CWA sometimes resulted in actions that private landowners protested were unfair takings of their property (see vol. 1, ch. 4). Each agency issued its own set of field guidelines on how to determine

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Box 4-B-How Wet Isa Wetland?: The Debate Over Which Wetlands to Regulate--(Continued)

what constitutes a jurisdictional wetland. Regulation varied considerablyfrom one jurisdiction to the next because separate regional offices of the decentralized Corps of Engineers interpreted or applied regulations differently, and some States were more active in overseeing wetland programs than others. Furthermore, changes by the Reagan administration intended to curtail the regulatory program by revising the Corps' procedures were opposed by many In EPA and FWS, leading to numerous conflicts over policy. By 1987, these differences made dear the need for a more coordinated national policy. Former EPA Administrator Lee Thomas requested that The Conservation Foundation, a private environmental organization, convene the Wetlands Forum in 1987 to try to resolve some of these issues. In 1983, this forum offered the idea for an interim goal of "no net loss" of wetlands with a long-term goal of a net gain in the quality and quantity of the Nation's wetlands.

A year later, the agencies were spurred to joint action. The Corps and EPA signed a memorandum of agreement detailing how they would meet the no-net-loss policy goal and encouraging more rigorous implementation of the Section 404 permit program. in addition, the Corps, EPA, FWS, and SCS adopted an lnteragency delineation manual to be used by the four agencies in making regulatory andprogram decisions (33). The manual was developed by a panel of wetland scientists and set mandatory technical criteria and suggested field indicators. Although the interagency manual changed little in the Section 404 policy, it did result in a more **coordinated and** uniform application of the 404 program nationwide. Because it was not an official policy document, the manual was adopted without public notification and comment, which rankled those regulated.Th ey complained that the manual was too technical and difficult for people who had to delineate wetlands-in some jurisdictions, the landowners themselves. The groundswell of dissatisfaction was effectively consolidated by a series of public hearings convened across the country by the President's Council on Competitiveness. Protests gradually grew more vocal and more organized, and eventually led to the Administration decision to issue the revised manual that became the center of so much controversy in 1991.

Although the 1989 manual was accused by some of being too technical, it had at least won the support of the scientific community. The 1991 revision did not enjoysuch scientific support. During the revision, the chief ERA scientist onthe panel resigned, protesting that modifications demanded by the White House and some members of Congress were politically motivated rather than scientifically sound. Federal agencies such as the Office of Management and Budget and the Council on Competitiveness assumed major rolesinthe revision, further fueling suspicions by scientists and environmentalists and leading to a huge number of comments protesting the revised manual.

The regulatory question, "How wet is a wetland?" has still not been resolved. A revised manual is unlikely to be issued soon. In the meantime, EPA and the Corps have reverted to using the Corps' 1987 guidelines. The outcry over the manual has encouraged many States to become more active in their oversightof the Section 404 program, and some are preparing to assume primary responsibility for implementing the Federal programs, as many have done for air-pollution-control regulations. But whatever the resolution on the regulatory side, the debate has demonstrated the difficulty of reaching consensus on natural resource protection. The boundaries of a wetland will appear to be boated indifferent places depending on when in the moisture cycle it is examined: a wetland may not always be wet. Moreover, protecting only the obviously wet areas may fail to protect the ecosystem as **a whole** (2). Protection based on larger areas---watersheds or ecoregions bounded by their topography, hydrological systems, and biological characteristics---will be more Iikely to maintain the function of wetlands and other important ecosystems.

SOURCES: J.A. Kusler, "Wetlands Delineation: An Issue of Sciences or Politics'?' Environment vol.34, March 1992, pp. 7-11, 29-37; J, Alper, "War Over the Wetlands: Ecologists v. the White House,"Science, vol. 257, August 1992, pp. 1043-44; J.P. Cohn, 'How Wet Must a Wetland Be?" Government Executive, vol. 24, March 1992, pp. 20-25; C. Copeland, Federal Wetlands Manual Revisions:Summaryof Interagency Team Reports (Washington, DC: Congressional Research Service, Library of Congress, Feb. 25, 1992); U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, "Proposed Revision to the Federal Manual for Delineating Wetlands," *Federal Register, vol. 56, Aug.* 14,1991, pp. 404446-80.

wetlands can help control coastal erosion and flooding that may result from accelerated sea level rise (see vol. 1, ch. 4). Wetlands will help absorb and slow water runoff in urban areas that may result from more frequent and intense storms. In areas that become drier, concentrations of pollutants may be higher in runoff and surface water (see vol. 1, ch. 5). Wetlands will help falter out these pollutants and improve water quality. They may also become even more important as habitats for fish, waterfowl, invertebrates, and other wildlife under various warming scenarios.

Wetlands are not protected by any single Federal law or regulation, but by an amalgam of programs at all levels of government, many of which might be called on to cope with the impacts of climate change on wetlands. Federal programs over the past 50 years have focused on protecting existing wetlands through acquisition and, starting two decades ago, regulation. More recently, as the loss of wetlands has continued, interest has also turned toward restoring degraded and drained wetlands and creating new ones.

Section 404 of the Clean Water Act (CWA; P.L. 92-500) has played a limited but contentious role in the protection of wetlands. As one part of the broad CWA program to maintain the chemical, physical, and biological integrity of the Nation's waters, Section 404 regulates the discharge of dredged or fill material into waters of the United States, including wetlands. However, Section 404 effectively covers activities responsible for just one-fifth of the area of wetlands that disappears each year (112). Attempts to tighten direct Federal regulation of other wetlands have been constrained by the perception that strong restrictions on privately owned wetlands could, under appropriate circumstances, constitute a *taking*, which requires compensation (see vol. 1, ch. **5).** With nearly three-quarters of all remaining wetlands in private hands, an appropriate structuring of Federal incentives for activities on private lands is an essential complement to existing strategies for regulating wetlands (25). Incentive programs include direct payments, removal of various Federal subsidies, and *tradable rights* provisions such as mitigation banking (discussed below).

State and local regulations, including zoning and land-use controls, and efforts by private conservation organizations are essential to an overall strategy for protecting wetlands, both now and as the climate changes. However, because this report focuses on Federal programs, discussion of State and local activities is limited to considering how Federal programs might encourage or coordinate-or at least refrain from hindering-efforts at other levels.

A program designed to protect and regulate wetlands on almost any scale will be most effective if it incorporates an integrated approach to evaluating and managing wetlands within the context of the watersheds and hydrological systems in which they are located. Decisions on how to balance loss of wetlands against the need for development and other activities can best be made when decisionmakers have a clear understanding of the particular functions and values of a wetland within a given watershed-whether for wildlife habitat, flood control, water quality, or recreation, for example-and of how important that site is compared with other natural areas in the same vicinity that offer similar or complementary functions and values. An integrated approach to protecting wetlands will likely become even more important under a changing climate because the value of functions such as flood control and maintenance of water quality may increase in many areas due to changes in storms and hydrological regimes (see also vol. 1, chs. 4 and 5).

Whether wetlands change, migrate, or decline in response to climate change will depend largely on how humans decide to protect and restore wetlands now and in the future. Because loss of wetlands has already been extensive and degradation continues, many coastal wetlands and some inland wetlands are unlikely to be able to adapt to climate change--and a net loss of U.S. wetlands will occur. The existing Clean Water Act seeks to restore and maintain the physical, chemical, and biological integrity of the Nation's waters. To achieve the act's goals, existing wetlands should be protected from destruction or degradation to the maximum extent practicable; formerly destroyed or degraded wetlands could be restored as part of watershed-based plans. Current and future protection policies must be tailored to anticipate the effects of climate change and to maximize the adaptability of the wetland systems that exist now.

This chapter summarizes the current location and status of wetlands in the United States, outlines the fictions and products they provide, and describes the legislative framework under which they are regulated and managed. The ways in which wetlands might be affected by climate change and whether they will be able to adapt to it are also addressed. Finally, the chapter suggests various policy responses that could help maintain a full range of functioning wetlands.

U.S. WETLANDS TODAY

■ What Are Wetlands?

Wetlands are dynamic systems, characterized as much by constant processes of change as by any truly constant features (see box 4-C). Wetlands are often difficult to recognize or define precisely because the boundary between wet and dry in the continuum from open water and lands that are always wet *(aquatic ecosystems)* to upland areas *(terrestrial ecosystems)* that are often dry is rarely discrete. In general, however, most scientists agree that wetlands can be defined by the composition of the vegetation, the soil characteristics, and the presence of water at or

Box 4-C-Wetland Types and Distribution

Wetlands are usually categorized according to their characteristic vegetation, their location(coastal or inland), and the salinity of the water they contain (ranging from fresh to brackish to salt water). Ecologists have developed a comprehensive technical classification of U.S. wetlands (22); these areas are described in the broadest categories in general vernacular terms below.

Coastal salt marshes grow along relatively calm, low-lying coasts of the Gulf of Mexico, the Atlantic, and sores parts of the Pacific (with the greatest expanses occurring on coasts in the Southeast), and are alternately inundated and drained by the rise and fall of the tides. The relatively small number of plant species that can tolerate the extremes in temperature and the continuous changes in water level and salinity consist primarily of Spartina grasses.

Mangrove swamps along the Atlantic and Gulf coasts in Florida (southwestern Florida harbors the largest expanses) and in a few patches in Louisiana and Texas contain any of several species of salt-tolerant trees and take the place of salt marshes in areas that are mostly free from frost

Tidal freshwater marshes occur in the upper reaches of tidal zones in estuaries along the Atlantic, Gulf, and Pacific coasts, but are most common in the mid-Atlantic region, Texas, and Florida Vegetation includes both **grasses and** broadleaf species and maybe extremely diverse and productive in the upper reaches of the marsh.

Freshwater nontidal wetlands comprise 95 percent of the Nation's vegetated wetlands. They may occur at any latitude but are not common at very high altitudes. Water depths of these wetlands usually range from 6 inches to 3 feet (from 0.15 to 0.90 meters)[1] and vegetation is generally characterized by soft-stemmed plants, grasses, sedges, and rushes. These include common plants such as waterlilies, cattails, reeds, arrowheads, and pickerel weed. Most of these wetlands serve vital storm-water and water-quality-control functions.

Inland depressional marshes may be either freshwater or saline. The freshwater marshes are most commonly found in depressions in the Great Plains States (prairie potholes), in Florida, and in California (vernal pools) and

1 To convert inches to meters, **multiply by *0.025;*** to convert **feet to meters, multiply by 0.305.**

have water depths ranging from several inches to 3 feet. Vegetation consists of soft-stemmed plants--grasses, sedges, and rushes, such as waterlilies, cattails, reeds, and wildrice-that emerge above the water surface. The saline marshes occur primarily along shallow lake basins and other depressions in the arid western United States, and include playas and rain-basin wetlands. These marshes are generally saturated with water and maybe 2 or 3 feet deep during the growing season. Plant life includes hard-stemmed or alkali bulrushes, widgeon grass, and sago. Many of these wetlands are semipermanent or seasonal, and some are found only occasionally during wet years.

Peatlands, including bogs and fens, are found throughout the Upper Midwest and in the Northeast, as well as in North Carolina and Honda, in shallow lake basins and flat uplands and along slow-moving streams. The soil, which is often composed of peat and maybe covered by moss, is generally saturated with water and may support both woody and herbaceous plants. Typical vegetation in northern bogs includes cranberries, leather-leaf, Labrador tea, and cotton grass, whereas southeastern bogs (known as pocosins) harbor pitcher plants, pond pine, Cyrilla, Persea, ***Gordonia,*** sweet bay, and Virginia chain fern. Bogs are typically valued for their production of renewable resources such as blueberries and cranberries, and can also be used as a source of peat and sphagnum moss for use in agriculture and horticulture. In some areas, the water-purifying properties of bogs are also important. Bogs are home to various insectivorous plants, which are valued for their scientific interest and as exotic house plants. Several varieties of these plants, including hooded and golden pitcher plants, are threatened or endangered species.

Tundra is a wet grassland found in cold climates, either at high altitudes on mountains *(alpine tundra) or* at northern latitudes *(arctic tundra).* Up to 25 percent of the State of Alaska is covered by arctic tundra and alpine tundra cart be found in the Rocky Mountains in the West and in the White Mountains in New England. Tundra generally has a deep layer of water-saturated soil that is permanently frozen (pemafrost), covered by a thick, often water-saturated mat of living and decaying vegetation including lichens, sphagnum mosses, grasses, sedges, and dwarf woody plants.

Shrub *swamps* are found along slow-moving streams and floodplains throughout the Southeast and Upper Midwest. The soil, which is often saturated during the growing season and may flood up to 6 inches deep, supports vegetation such as alder, willows, and dogwood.

Wooded swamps may be found alongside sluggish streams, in floodplains or shallow lake basins, and on flat uplands in the Southeast and Upper Midwest. The Soil is generally water-saturated during most of the growing season, and may be covered by up to 2 feet of water during periods of heavy rain or flooding. Typical northern vegetation includes tree species such as tamarack, white cedar, balsam, red maple, and black ash, often accompanied by a thick covering of moss, whereas further to the west, willows, red alder, and western hemlock are more common. In the South, vegetation may feature water and overcup oak, tupelo gum, swamp black gum, and cypress.

Bottomlands and other riparian habitats are found in low-lying floodplain areas adjacent to rivers throughout the eastern and southern United States as well as the arid West. These areas are not always recognized as wetlands because they are not necessarily water-saturated throughout the full growing season and they may only have standing water after an occasional flood. In the South, the lowest areas are characterized by hardwood trees such as bald cypress, tupelo gum, and water elm Higher areas that are less-frequently flooded support red maple, sweet gum, and various types of oak. The most infrequently flooded sites contain shagbark hickory, swamp chestnut oak, and post oak. In the West, riparian habitats are widely scattered along the permanent and intermittent rivers and streams that course through the arid and semiarid terrain; common trees include willows, alders, cotton woods, salt cedar, and mesquite.

SOURCES: R. Brewer, *The Science of Ecology(Philadelphia: Saunders* College Publishing, 1988); U.S. Department of the Interior (DOI), Fish and Wildlife Service (FWS), An *Overview of Major Wetland Functions and* Values, FWS/OBS-84/18 , contractor paper prepared by J.H. Sather and R.D. Smith (Washington, DC: U.S. DOI, FWS, September 1984); US. Congress, Office of Technology Assessment, Wetlands: Their *Use and Regulation,* OTA-0-206 (Washington, DC: U.S. Government Printing Office March 1984); R.S. Warren, "Coastal Wetland Vulnerabilities to Climate Change," contractor report prepared for the Office of Technology Assessment, July 1992.

near the soil surface for some part of the year. These elements are set forth in the definition of wetlands used by the U.S. Fish and Wildlife Service (FWS) as the basis for the National Wetlands Inventory (22) (several similar but distinct definitions are used by other agencies for regulatory purposes (see box 4-D)):

Wetlands are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. The single feature that most wetlands share is soil or substrate that is at least periodically saturated with or covered by water . . . **Wetlands are lands**

Box 4-D--Why Care About Wetlands?

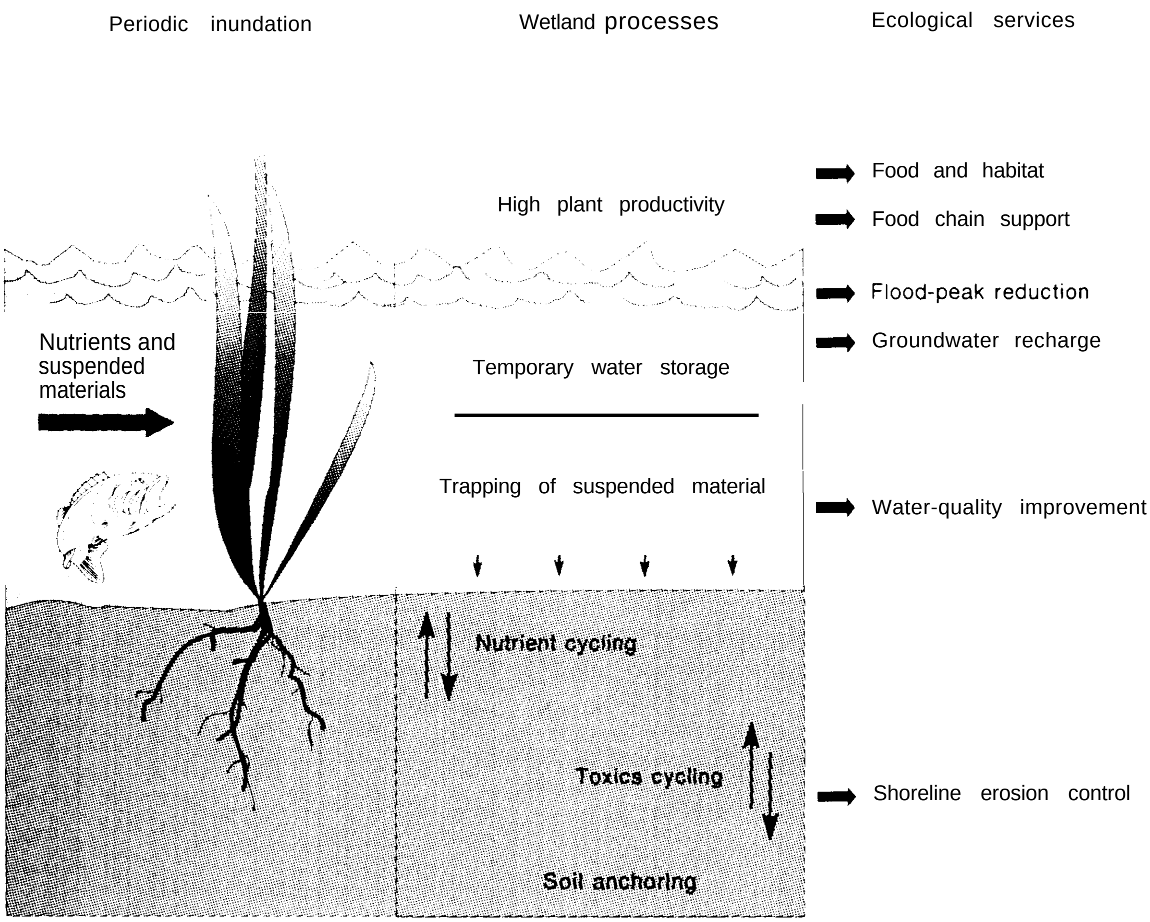
Wetlands are a resource of tremendous yet sometimes unrecognized, economic importance. The jobs of commercial fishers rely on wetlands---75 percent of the commercially landed fish **and** shellfish are dependent on ***wetlands*** (14). Sport fishing and waterfowl hunting, both of which depend on wetlands, generate several billion dollars of economic activity annually, offering significant stimulation to local economies. Commercial trappers make their living from wetlands, with over a third of the furs harvest in the United States coming from mammals that live and grow in wetlands. **Millions of dollars in** flood damage and pollution control may be averted by the presence of healthy wetlands. Wetlands provide crucial habitat for many endangered species. They also provide an environment highly valued for its aesthetic and recreational enjoyment

The degree to which and the frequency with which a wetland performs these various functions depend largely on where it is located. For example, although all wetlands perform some water filtration, this function is valued more where runoff waters are polluted than in pristine areas. Similarly, although nearly all wetlands provide wildlife habitat, the significance of that habitat varies. Some Wetlands provide major societal benefits only occasionally, such as the floodplains and t emporary ponds that may store or slow runoff during heavy rains or flooding, but may not even appear to be wetlands during dry years. Furthermore, value is in the eye of the beholder. A resident of a flood-prone area may value nearby wetlands because they attenuate floods and may eliminate the need to construct walls or ditches to control floods, whereas **a mare** distant resident may value the same wetland more for its aesthetic and recreational values.

The loss of these functional values usually comes at **an expense to the surrounding area Removing or** degrading a wetland that serves an important flood-control function will require investment in additional storm-water controls or replacement of property and resources damaged by floods. Degradation **of a wetland that serves a prims water-filtration function will** require additional investment in wastewater treatment facilities in the long term. By the same token,loss of valuable wetland wildlife habitat will result in a decrease in species. Though it is difficult to quantify these values, their loss certainly results in reverberating effects on surrounding communities and the landscape.

Economic values of wetlands are difficult to calculate and vary widely among different types of wetlands and the particular functions and products they provide. An array of approaches has been used to assess the values. Some studies have examined one or several services that wetlands provide to society, such as removing pollutants, providing flood control, or slowing coastal erosion, then have calculated the dollar value necessary to construct and operate sewage treatment plants or flood-control barriers that would perform equivalent services; the value of a wetland is assumed to be equal to the cost of replacing these services. Such studies have arrived at replacement values ranging from hundreds to hundreds of thousands of dollars per acre (70, 71, 89, 116). However, market values of wetlands rarely reflect the full replacement values indicated in such studies. Furthermore, despite numerous attempts, many values defy quantification. The value of habitat provided by wetlands for endangered species, for example, cannot easily be translated into dollar figures, but can only be hinted at through often-criticized surrogate pricing methods, such as surveys of the public's willingness to pay. Wetlands clearly make huge indirect contributions to the national economy through their roles in supporting the

Relationship Between Wetland Processes and Values



SOURCE: U.S. Congress, Office of Technology Assessment, *Wetlands: Their Use and Regulation,* OTA-O-208 (Washington, DC: U.S. Government Printing Office, March 1984).

multi-billion dollar U.S. fisheries and recreation industries, but pinpointing the proportion of valueadded by wetlands to these industries is difficult. Although scientists and economists may not agree on such dollar values, moat do agree that wetlands provide important functions, services, and products. Some of the major ones are outlined below.

Fisheries habitat—inland and coastal wetlands are essential to maintaining fish and shellfish populations. Billions of dollars a year are generated by the associated sport and commercial fisheries. About three-quarters of the commercial marine harvest consists of fish and shellfish that depend on wetlands--with regional estuarine dependency ranging from 98 percent for the Chesapeake Bay and 78 percent for the Gulf Coast to 76 percent in Alaska and 52 percent in the Pacific Northwest (14). In 1980 in Louisiana alone, the crayfish harvest amounted to $11 million (56). The Department of Commerce estimated in 1987 that the fish products from coastal wetland areas contribute more than $10 billion per year to the gross national product (GNP; 100). The value of marine

(Continued on *next page)*

Box 441-Why Care About Wetlands?--(Continued)

Economic Values of Wetlands

Function or service	Selected dollar value estimates per year
Fisheries habitat	Commercial fisheries harvest: $10 billion; marine recreational fishing: $13.5 billion
Waterfowl habitat	Recreational hunting: $638 million
Recreational activities	Spending on recreation: $55 billion
Flood and erosion control	$2,025/acre [a]
Pollution filtering	$400/acre
Timber and specialty crops	Standing timber value: $8 billion; cranberry, blueberry, wild rice harvest value: unknown
Trapping	Fur-bearing-mammal harvests: $295 million; alligator hides: $1.7 million

[a]To convert acres to hectares, multiply by 0.405.

SOURCE: Office of Technology Assessment, 1993.

recreational fishing (both shellfish and finfish) has been estimated at $13.5 billion (3). In addition, nearly all freshwater fish depend on wetlands for food and spawning grounds.

Waterfowl habitat--Wetlands are crucial to the existence of many birds. They are especially important as breeding grounds, feeding grounds, and wintering areas for migratory waterfowl. The hunting of waterfowl is a major wetland activity. In 1980,5.3 million people spent $638 million hunting waterfowl (WVS estimate cited in ref. 56).

Recreational activities--Wetlands support a range of recreational activities such as boating, birdwatching, and hiking in addition to hunting and fishing. The majority of these activities depend on wetlands with healthy vegetation (108). Wildlife refuges that contain wetlands, such as the Okefenokee Swamp in Georgia and Sanibel Island in Florida are among the most frequently visited of the lands managed by the U.S. Fish and Wildlife Service (FWS) (95).[1] FWS estimated that in 1980, recreational users spent $148 million observing and photographing fish and wildlife in the United States (56). A 1985 survey of fishing, hunting, and wildlife conducted by FWS estimated that overall “141 million Americans participated in wildiife-associated recreation, and spent $55 billion” (108), and an estimated 17 million sport anglers spent $8.2 billion (78).

Flood and erosion control--Inland wetlands decrease erosion by slowing runoff and by trapping sediment. They also limit flood damage by serving as a buffer zone and by absorbing the energy from overflows. Coastal wetlands act to slow erosion by buffering wave action and by trapping and anchoring sediment to the shore. Like inland wetlands, they also aid in flood control, reducing the destructive energy of waves and storm surges. The value of flood control and shoreline protection can be estimated by calculating the potential costs avoided. For example, a 1972 study by the Army Corps of Engineers determined that protecting 8,422 acres (3,389 hectares)[2] of wetlands adjacent to the Charles and Neponset River watersheds in Massachusetts could prevent more than $17 million in flood damages (106). In the Midwest, the Mississippi has been artificially controlled for years to provide land for agricultural and other uses, and its flood-control capacity has been dramatically decreased, resulting in exorbitant damage costs.

Pollution filtering--Wetlands contribute to water quality by trapping sediment and pollutants before they enter waterways. These areas are particularly helpful in reducing excess burdens of nitrogen and phosphorus that may otherwise cause harmful overgrowths of algae. A study in Georgia estimated that one 2,500-acre marsh, if given the opportunity, could have performed around $1 million in water pollution control per year. This suggests a value of $400 per acre per year for that wetland’s pollution-control services.

1 J.W. Beaver, Biological Scientist, Florida Game and Fresh Water Fish Commission, personal communication, May 13-14, June 1,1932.

2To convert acres to hectares, multiply by 0.405.

Timber and specialty crops--Bottomland wetland forests of the southeastern United States have a standing value of some $8 billion. Hardwood timber harvests from bottomland forests can be accomplished with minimal harm to wetlands. Other wetland areas in the South support rice farming and aquaculture. Wetlands in the Northeast and North Central States provide cranberries and blueberries, and some North Central wetlands also *grow wild rice. Grasses* in wetlands also serve as livestock feed in many areas of the country, particularly along rivers and streams in the arid West.

Trapping--Both the coastal and inland wetlands provide valuable habitat for fur bearers and reptiles. Fur-bearing mammals that live in wetlands include beavers, muskrats, raccoons, minks, *and* otters; FWS estimated the harvest of these mammals from wetlands to be $295 million in 1980 (nearly one-third of the industry's total). The sale of alligator hides that year generated an additional $1.7 million (56).

Endangered species habitat-More than one-third of the United States's threatened and endangered species use wetlands as their primary habitat (69), and numerous others rely on wetlands during some part of their life cycles. Wetlands are necessary for the survival of such species as the American crocodile, the whooping crane, the wood stork, the bald eagle, the manatee, the insectivorous hooded pitcher plant, and many others.

Carbon sink--Because of their high productivity, many wetland systems are very effective at storing, or sequestering, carbon. Soils in tundra (and other northern ecosystems) may store up to one-third of the global pod of carbon now stored in soils (which could, if released to the atmosphere, speed up climate change) (72). Coastal wetlands, such as salt marshes, also store significant amounts of carbon (27).

Other cultural and aesthetic values---Wetlands hold many sites of historical and archaeological value and offer opportunities for education and scientific study. The combination of land and water gives wetlands a unique aesthetic appeal (120).

SOURCES: U.S. Congress, Office of Technology Assessment (OTA), *Wetlands:* Their Use and Regulation, OTA-0-206 (Washington, DC: U.S. Government Printing Office, March 1984); U.S. Department of Commerce, Letter of Comment, dated Nov. 27, 1987, on the Sept. 1, 1987, Draft Wetlands Priority Plan; U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA), *National* Marine Fisheries Service (NMFS), Fisheries of the United States, 1990, Current Fishery Statistics No. 9000 (Silver Spring, MD: Fisheries Statistics Division, NMFS, NOAA May 1991).

> transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. . . [W]etlands must have ***one*** or more of the following three attributes: 1) at least periodically, the land supports predominantly hydrophytes [plants that can grow in water-saturated soil]; 2) the substrate is predominantly undrained hydric soil [soil that displays properties associated with having been saturated with water]; and 3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year,

How to apply this definition, or some variation of it, has generated considerable controversy, particularly in attempts to define the boundaries of wetlands subject to Federal regulation (see box 4-E).

Wetlands can be classified according to many different characteristics, such as whether they are inland or coastal, fresh or saline. However classified, wetlands cannot be considered in isolation from the landscapes and the larger context of the hydrological systems in which they exist, such as the estuarine and inland landscapes shown in figure 4-1 (68, 120; see also ch. 2). Because wetlands are intricately connected to the quantity and quality of water flowing through a watershed, they are susceptible to any climate-induced changes in temperature and precipitation that affect the amount, speed, or temperature of water in the system. Their close link to hydrological cycles also means that they both affect and are affected by human activities in surrounding areas. For example, wetlands that occur in sites where an aquifer discharges water at the surface may be affected if the aquifer is depleted or reduced by decreased precipitation, runoff, and increased evaporation, or by human activities such as

Box 4-E-Is a Wetland a Place or a Process?

Part of the difficulty of regulating and protecting wetlands is that they are, by nature, dynamic systems. Wetlands may follow a progression from being fully or partially saturated, through a period d uring which vegetative material gradually accumulates, to being saturated less frequently, allowing for different species to move in. Many are only seasonally or periodically wet. Or the opposite may occur---a wetland may gradually or suddenly become saturated as a result of changes in water flow or levels in a lake, river, or estuary and eventually convert to open water. A recent report by the National Academy of Science (68) states:

> Along the edges of rivers, newly deposited sediments will be readily invaded by opportunistic plants and animals. Initial colonists are unlikely to be the same species as those of the floodplain forest that eventually develops. Along the edges of continents, mud fiats are formed by alluvial outwash **and are** gradually colonized by salt marsh grasses and succulents, which in turn trap sediments that raise the topography and attract additional plant and animal species. Along the edge **of an acidic lake, sphagnum moss and** herbaceous plants develop a mat that eventually supports bog shrubs and bog forest trees. in all these habitats, the nutrient content of the soil and the biomass of plants and animals increase through time, along with increases in species diversity and ecosystem complexity.

Yet U.S. policyhas tended to treat wetlands,like many other natural lands, as if they were static systems that will stay in the same place indefinitely if only further development is prevented. The Government has designated National Parks, National Wildlife Refuges, National Estuarine Research Reserves, and National Marine Sanctuaries as places where wetlands will be protected, but these areas are often surrounded by intensive land use **and development,** which may limit the ability of wetlands to continue their processes of growth **and** evolution (see vol. 1, ch. 4). in many parts of the Nation today, the natural processes of wetland evolution can no longer take place: "Before the widespread impact of man, new wetlands would have regularly opened up---due to the changing flow of a river for example--replacing those lost by succession or changes in drainage patterns.... In our modern, human-dominated world, however, where rivers and coastlines are constantly being molded to suit our whims, the natural recruitment of new wetlands is lost, depriving wildlife of a vital habitat . . ." (41).

Where does climate change fit into the picture? By speeding up the rate at which the elements of the environment change---the temperature, precipitation, and water-flow patterns, for example--climate change will require that the processes of evolution and the migration of species that inhabit wetlands take place more rapidly to keep up. In areas where there remains room to grow, where human activities have not yet blocked the paths for a natural progression of wetlands, the wetlands maybe able to adapt in time. But regardless of the initial causes of loss or degradation, in places where human activities have raised impenetrable barriers, the natural processes of wetlands may simply be squeezed out.

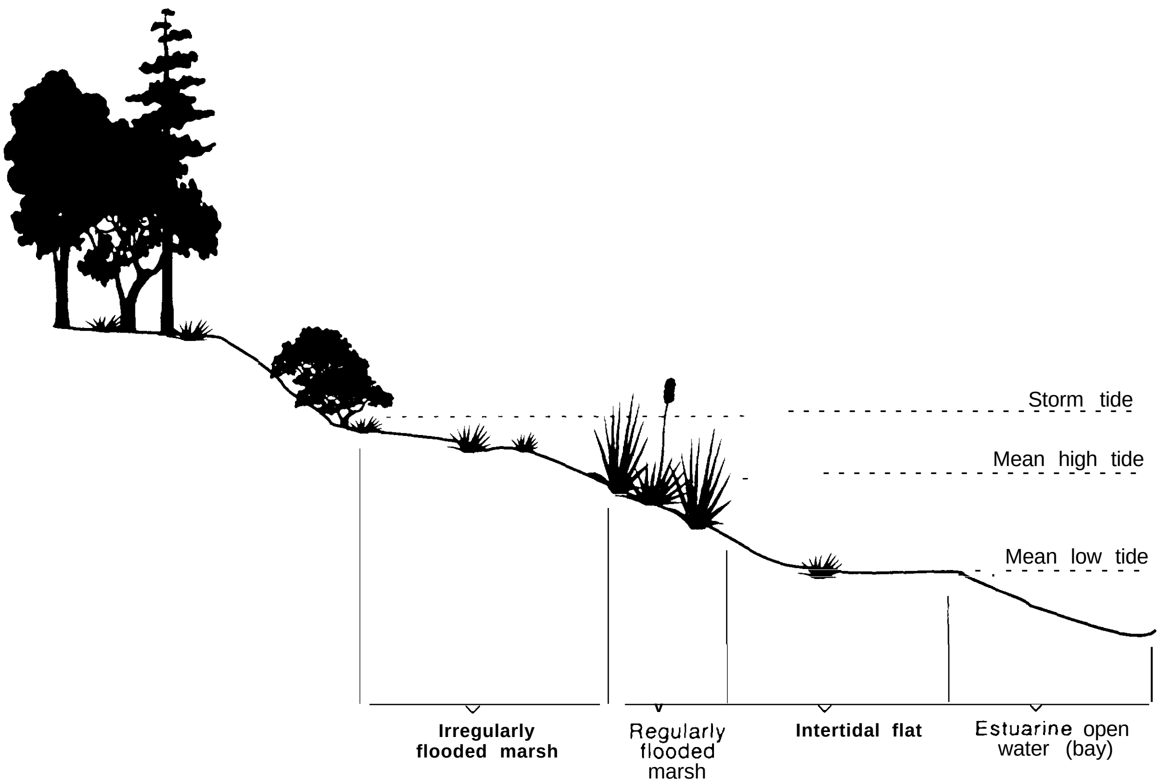
SOURCES: E. Goldsmith, N. Hildyard, P. McCully, and P, Bunyard, Imperiled Planet:Restoring Our Endangered Ecosystems (Cambridge, WThe MIT Press, 1990); National Research Council (NRC), Committee on Restoration of Aquatic Ecosystems --Science, Technology, and Public Policy, Water Science and Technology Board, Commission on Geosciences, Environment and Resources, Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy(Washington, DC: National Academy Press, 1992).

pumping water for irrigation and municipal use. Likewise, destruction of a wetland may cause downstream changes in flooding or water quality and degrade the quality of habitat for fish and wildlife. Attempts to manage, protect, or restore wetlands must take into account the numerous and intricate interactions among different parts of the landscape and must recognize that wetlands make up just one part.

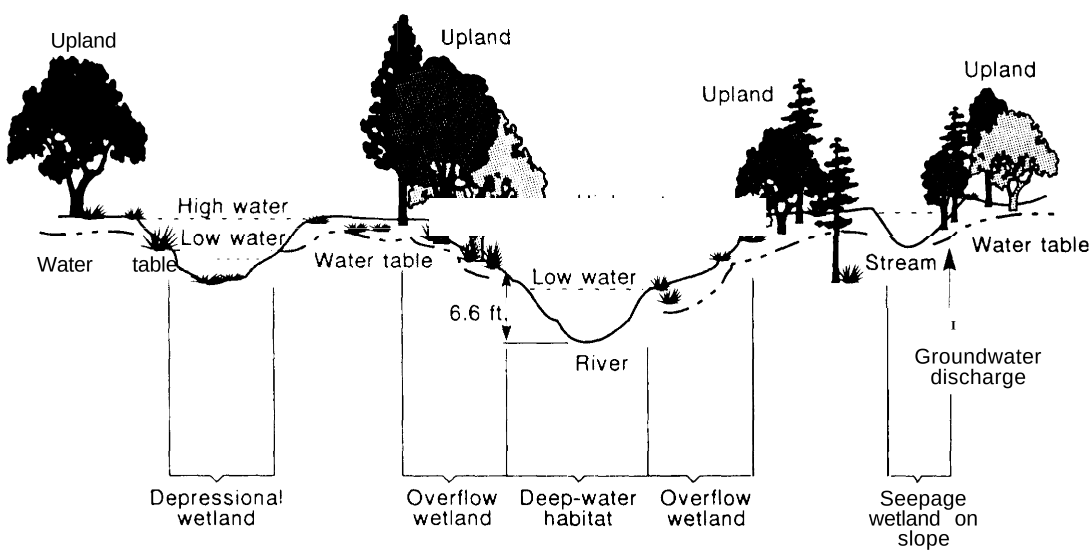
■ Why Are Wetlands Important?

Wetlands provide diverse products of considerable commercial value, playing a key role in the production of goods such as finfish, shellflsh, fur, waterfowl, timber, blueberries, cranberries, wild rice, and peat (see box 4-D). Wetlands also nurture biological productivity, slow surface-water flows, transform nutrients and toxic chemicals, and provide habitat that often harbors high

Figure 4-l-Cross-Sectional Diagrams of a Northeastern Salt Marsh and a Riparian Wetland System



NOTE: Intertidal flats are only intermittently inundated, depending on tidal movement; irregularly flooded marshes are usually brackish because they serve as a transition zone between the coastal marsh and the upland.



NOTE: Overflow wetland areas are transitional between the wetland and the upland, are periodically Inundated, and provide a vital flood-control function; depressional wetlands, or glacial pools, which are often filled in for agricultural use, occur in the prairie-pothole region in the Midwest. To convert feet to meters, multiply by 0.305.

SOURCE: R.W. Tiner Jr., *Wetlands of the United Stares: Current Status and Recant Trends*, National Wetlands Inventory (Washington, DC: U.S. Department of the Interior, U.S. Fish and Wildlife Service, March 1984).

biodiversity (described in more detail in ch. 2). These ecological functions are often associated with functions that are more directly valued by humans, such as flood control, erosion reduction, and improved water quality. Wetlands are also considered valuable for their aesthetic appeal and their recreational and educational opportunities. More recently, wetlands have become valued for their ability to store carbon (see ch. 2). They are critical habitat for about one-third of the Nation's threatened and endangered species (57); some species use them periodically (daily or seasonally) for food and water, whereas others reproduce in wetlands, and still others spend their entire life cycles there.

The many values of wetlands are closely interrelated (see box 4-D). For example, the aquatic plants in estuarine wetlands provide food and shelter for numerous finfish and shellfish, including many species valued for commercial, sport, and subsistence fishing. The vegetation and associated animal life also attracts waterfowl, which may lure hunters, birdwatchers, photographers, weekend boaters, and students on field trips. Such uses may profit local businesses and manufacturers that provide recreational services and products such as boats, binoculars, cameras, hiking boots, guns, and fishing gear (68, 95, 106, 120).

Where Are Wetlands Found?

In the mid-1980s, approximately 103 million of nearly 2 billion acres (41 million of 0.8 billion hectares)[2] of the conterminous States were occupied by wetlands (24). Roughly 5 percent of the lower 48 States is covered by wetlands, which is less than half the area of wetlands estimated by FWS to have covered those States during colonial times (23, 24). About 95 percent of total wetlands are inland freshwater wetlands[3] and only 5 percent are saltwater in coastal areas and estuaries. Approximately 75 percent of all wetlands in the conterminous States are privately owned (108), and the remainder belong to parks, wilderness areas, forests, and refuges held by Federal, State, and local agencies. Alaska has approximately 170 million acres of wetlands, comprising around 45 percent of the interior area of the State; approximately half of this consists of arctic tundra. Hawaii contains approximately 7,000 acres of wetlands, less than 0.2 percent of its total land area (23). The different types of wetlands and their geographical distribution are summarized in box 4-C and displayed in figure 4-2.

Why Are Wetlands Becoming Degraded?

Climate change is only one of numerous human-influenced environmental factors that impose increasing pressures and demands on natural ecosystems, including wetlands. These factors can be primarily chemical, physical, or biological in nature, or any combination. Like many natural areas, wetlands are degraded by air and water pollution, including industrial air emissions, contaminated waters from urban or industrial landfills, runoff laden with agricultural chemicals, contaminated irrigation water, and salinization from road salt. Inland and coastal wetland areas alike may be affected by water diversions and the altered water and sediment flows that result from channelization and navigation projects, flood-control structures, upstream withdrawals, and the pumping of water from aquifers

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2 To convert acres to hectares, multiply by 0.405.

3 FWS defines coastal wetlands narrowly to include primarily tidal wetlands. A recent report by the National Oceanic and Atmospheric Administration (NOAA) on coastal wetlands used the same database but defined coastal wetlands more broadly to include "wetlands within watersheds or drainage areas directly surrounding estuarine waters or within counties adjacent to marine waters" (101). According to this definition NOM calculates that coastal wetlands account for nearly one-third of the Nation's total area of wetlands (almost 27.4 million acres), and that wetlands occupy 16 percent of the total land in coastal areas.

Figure 4-243 General Distribution of Wetlands in the United States

NOTE: Shaded portions incorporate general wetland areas,

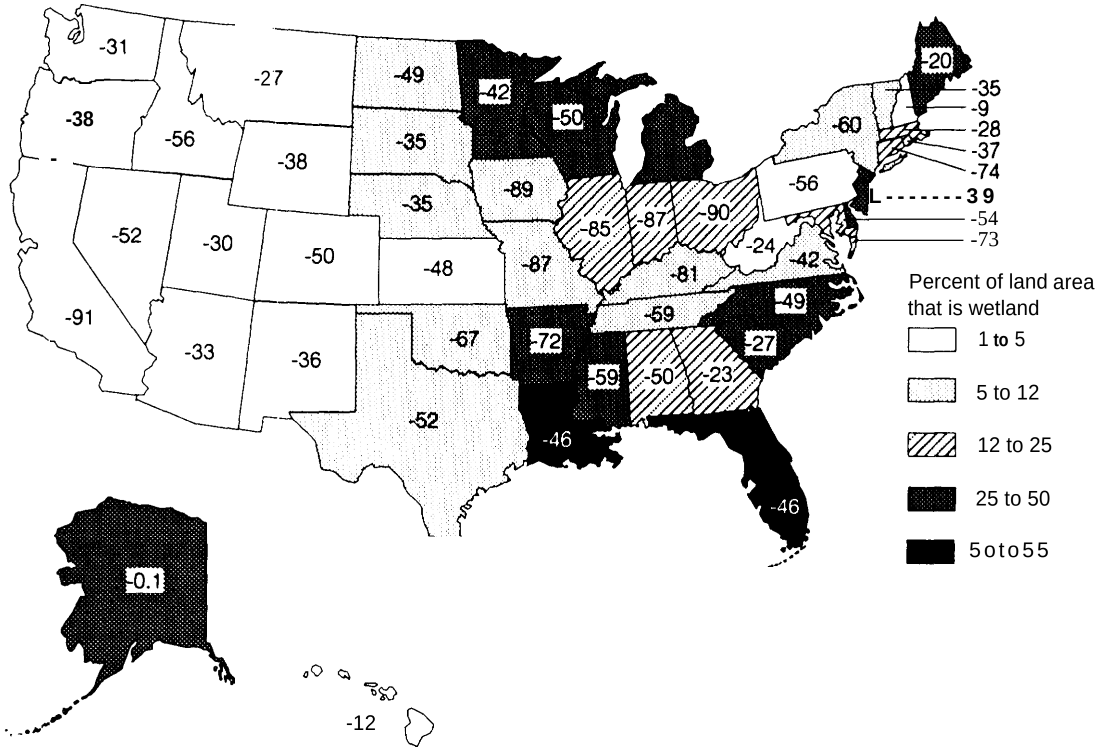
SOURCE: R.W. Tiner, Jr., *Wetlands of the United States: Current Status* and *Recent Trends*, National Wetlands Inventory (Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, March 19S4).

for municipal and industrial use.[4] Construction of public-works projects (e.g., roads, airports, power plants, and darns) and private buildings (housing developments, office buildings, and marinas), and land-management practices (grazing, logging, and mining) in or near wetlands may all degrade or destroy them. These activities can also alter stream flow and sedimentation patterns by cutting off vital freshwater or sedimentation flow or by changing the balance of freshwater and salt water in estuarine areas (95, 112). Alterations of water levels and hydrological systems may in fact cause the most damage to wetlands (54).

Wetlands that are already degraded are often more susceptible to encroachment of *nonindigenous* (nonnative or exotic) species that may cause severe and sometimes irreversible damage to the habitat of native species. Coastal wetlands may be further affected by altered wave and current patterns created by the construction of dikes, sea walls, and other structures built to protect the coast, as well as by activities such as

[4] Although channelization and dredging projects may exert more-obvious pressures on wetlands, an increasing but less-obvious threat to inland marshes and swamps is the development of new well fields to supply municipal water in areas where the population is growing or in coastal areas (such as in Florida) where salt water has seeped into freshwater aquifers that were pumped down. Loss of wetlands due to well fields has not attracted research and monitoring efforts and is unlikely to be adequately accounted for in wetland inventories, but could become even more of a problem if climate change increases the intensity of well-field development (K.L. Erwin, Consulting Ecologist, Inc., personal communication, December 1992).

Figure 4-3-Wetland Acreage Lost in the United States, 1780s to 1980s



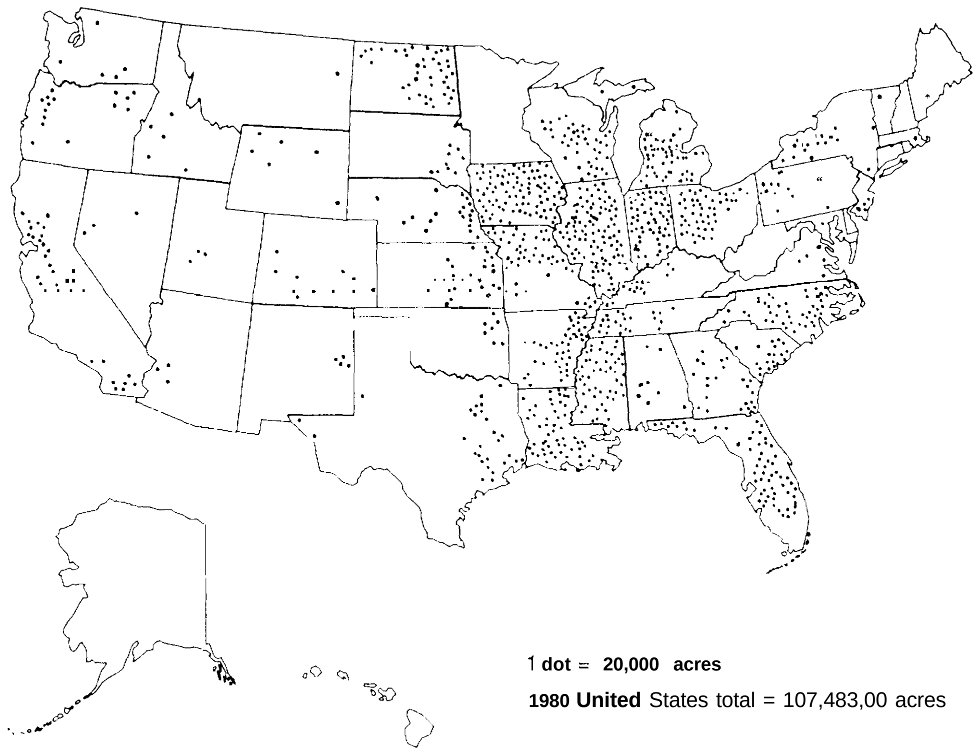
SOURCE: T.E. Dahl, Wetlands *Losses in the United States, 1780s to 1980s*, report to Congress (Washington, DC: Department of the Interior, Fish and Wildlife Service, 1990).

channelization, boat traffic, and subsidence following pumping associated with the off-shore extraction of nonrenewable resources (oil, gas, and groundwater) (46, 108, 113). FWS estimates that in the 1780s, wetlands covered more than 25 percent of the land area of 11 States; by the 1980s, as shown in figure 4-3 and box 4-D, only two States still contained 25 percent or more wetlands (23).

More than 80 percent of the destruction of wetlands aggregated over the past two centuries (1780s to 1980s) has been attributed to converting inland wetlands to agricultural uses, and agriculture remained the leading cause of loss from the mid-1970s through the mid-1980s. Figure 4-4 shows the extent and location of wetlands drained and converted to agricultural use as of 1985.[5] Although agricultural conversions have slowed, many wetlands could still be converted to agriculture. Around 5.2 million acres of wetlands are considered to have high or medium potential for

[5] Of the approximately 11 million acres of wetlands destroyed from the 1950s through 1970s, 87 percent were converted to agricultural uses (24)-an average rate of 480,000 acres per year-that were encouraged by various tax incentives and technical support. Between the mid-1970s and mid-1980s, however, the conversion of wetlands slowed to an average of 260,(X)0 acres per year, according to FWS estimates, due in part to decreasing rates of agricultural drainage and increased Federal Government regulation. Although agricultural conversions declined, they still accounted for 54 percent of the decade's losses (140,400 acres per year on average), while ''other'' land uses (that is, "lands that had been drained and cleared of vegetation but not put to an identifiable use' claimed 41 percent, and urban land uses were responsible for the remainder (24). New program have compensated for some losses of wetlands to agriculture by restoring some wetlands; the U.S. Department of Agriculture's Swampbusterprogram (described later in this chapter) added approximately 90,000 acres to the Nation's wetlands inventory from 1987 to 1990 (24).

Figure 4-4-Extent and Location of Artificially Drained Agricultural Land in the United States, 1985



NOTE: To convert acres to hectares, multiply by 0.405.

SOURCE: U.S. Department of Agriculture (USDA), Economic Research Service, "Farm Drainage in the United States: History, Status, and Prospects," Miscellaneous Publication 1455, G.A. Pavelis (cd.) (Washington, DC: USDA, December 1987).

conversion; the lands most likely to be converted are small wetlands that interfere with farming activities and larger forested wetlands that could be drained.[6] The U.S. Department of Agriculture (USDA) reports that "although some wetlands have been converted directly to agricultural uses, about half were originally forested and may have entered agricultural use after being cut over for timber" (99). This practice may be slowing due to economic trends (see box 6-D).

Even where wetlands remain because they have been protected, they are often fragmented into small acreages surrounded by agriculture or residential development. The fragmentation of wetlands and associated habitat interferes with many long-term processes associated with normal wetland functions, so their ecological functions are often diminished and their value as wetlands deteriorates (see box 5-D). Wetlands remain, however, an important component of federally protected natural areas, with 380 of 408 National Wildlife Refuges including substantial tracts of wetlands. Chapter 5 discusses in greater detail the issues surrounding federally protected lands of all types.

6 "High potential for conversion" means that "similar lands were being converted in the years preceding the inventory' (99).

SURVIVAL OF WETLANDS UNDER CLIMATE CHANGE

How Could Climate Change Affect Wetlands?

Scientists have not precisely quantified the intricate interactions between wetlands and climate. No single factor determines whether wetlands will be at risk from climate change or whether they can benefit. The variables that are predicted to change include temperature, precipitation, carbon dioxide (CO> concentrations, and sea level. Some predicted impacts are described in chapter 2 and summarized in boxes 4-F and 4-G and table 4-1.

Climate change will affect the ecological and other functions of wetlands, but the rate and magnitude of losses of functions and products may differ, and may not be closely linked. As described in chapter 2, the public's perception of the impacts on wetlands will be based primarily on products and nonecololgical functions. Fully accounting for and predicting the potential damages will require not only precise regional predictions about the rate and magnitude of climate change, but also site-specific information on the functions and products of wetlands and their links to climate. Because such information is scarce and precise regional climate predictions do not yet exist, this section offers a qualitative rather than a quantitative view of whether, and how, wetlands can adapt to climate change and discusses what will make certain wetlands vulnerable to climate stresses (see table 4-l).

Climate change could affect the distribution and condition of U.S. wetlands by reducing the area they cover and potentially altering the assemblages of plant and animal species they

NATIONAL WETLANDS INVENTORY, U.S. FWS

The Florida coast hosts many mangroves that are havens for a variety of wildlife and migratory waterfowl. These dynamic wetlands also serve to protect the shoreline from erosion and help to maintain water quality.

support; both changes could affect the functions and products for which wetlands are protected (see box 4-D and ch. 2). The time frame over which climate change will affect wetlands, and the manner in which their functions and products are altered, will vary widely from one region to the next.[7] In the short term (5 to 25 years), wetlands may be most affected by extreme weather events, such as unusually severe storms, floods, droughts, and fires, which may disrupt the growth of vegetation (see box 4-H). Although all of these are normal, natural events that shape wetlands, their impacts may be particularly severe in areas already disturbed by human activities. Over the longer term (25 to 100 years), changes will likely include shifts in species composition as space opened by disturbance from extreme events is occupied by new species. In areas that become drier, the edges of wetlands will start to recede, while the structure of wetlands

[7] The Office of Technology Assessment convened a 2-day workshop in May 1992 to identify wetlands vulnerable to climate change and to consider management strategies that could alleviate impacts. Participants included scientists and managers responsible for various aspects of research and policy on wetlands. The workshop yielded few conclusions about which wetlands and which functions and products may be lost first, other than a general observation that the subsiding coasts of the Gulf of Mexico are likely to be in trouble sooner and more seriously than the rockier coasts of the Pacific and North Atlantic. Although the workshop did not aim for consensus in any formal way, nearly all participants agreed that most functions of wetlands that humans value are vulnerable ❑ ow because so many wetlands have already been destroyed and their functions and products have diminished.

Box 4-F--Louisiana and Sea Level Rise: A Preview of What's to Come?

While coastal States up and down the Atlantic seaboard wrestle with what to do about impending sea level rise, the question is more than academic for Louisiana. A glimpse of the future is already here. Louisiana lost around 50 square miles (32,000 acres, or 12,800 hectares)[1] of its coastal wetlands every year between 1986 and 1978 as delta land subsided and the sea level rose, accounting for 86 percent of the entire Nation's annual losses of coastal wetlands. Since 1978, the annual loss has slowed to approximately 25 square miles. The figure below shows the dramatic decline of wetlands surrounding the mouth of the Mississippi from 1958 to 1978.

Wetland Changes in the Mississippi River Active Delta (1958-78)

NOTE: **The light shading designates marsh and forested wetlands, and the darkest shading designates upland and dredge-deposit areas. Between 1956 and 1978, there was a decrease of more than 50 percent in marsh and forested wetlands (about 100,000 acres lost in all) and an increase of almost 300 percent (about 12,000 acres gained) in upland and dredge-deposit areas. One inch equals 50 miles (1 millimeter equals 3 kilometers); to convert acres to hectares, multiply by O.405.**

SOURCE: U.S. Fish and Wildlife Service, National Wetlands Research Center, Slidell, LA, 1993.

The alarming erosion of Louisiana's coasts places at risk wetlands of great importance to fish and wildlife. Louisiana's coastal wetlands support nearly 30 percent of the Nation's commercial fish and shellfish harvests, provides the winter home for 20 to 25 percent of North America's puddle ducks, and yield North America's largest fur and alligator harvests. But Louisiana's coastal wetlands are important to Americans in other ways as well. The wetlands can reduce damage to property from hurricane-related tidal surges, provide flood storage when the Mississippi swells during large storm events, and remove pollutants from coastal waters.

Why the rapid decline? The coastal *lands of* Louisiana, like those in parts of neighboring Texas and Mississippi, were formed over millennia as sediment carried by the Mississippi River and its tributaries from States as far north as Minnesota, as far west as Montana, and as far east as Pennsylvania was deposited in the delta. The Mississippi spewed water, silt, dirt, and sand, until the debris had piled up so high that water no longer flowed easily seaward; the river then snaked around, changing its course, until it found the next path of least resistance. The loose sediments of these delta lands were gradually compacted and sank lower toward and into the sea,

1 To convert acres to hectares, multiply by 0.405.

(Continued on next page)

Box 4-F-Louisiana and Sea level Rise: A Preview of What's to Come?--(Continued)

eroding easily in the face of waves and storms, until wetland vegetation took root. Vegetation anchored the soil and built up organic material **and trapped** sediment and land started to accumulate again in coastal marshes. This dynamic process of deposition and growth continued until around a century ago, when human actions to control floods and improve navigation on the Mississippi began to drastically alter the hydrological patterns and interfere with the patterns of coastal and wetland growth. The consequences of human attempts to control alluvial processes are often dramatic, as was seen when the Mississippi scaled its artificial barriers and inundated hundreds of thousands of acres in its floodplain in July 1993--reclaiming, at least temporarily, many former wetlands.

The primary cause of Louisiana's wetland losses has been the construction of Federal and nonfederal flood-control levees along the Mississippi River that have virtually eliminated the inflow of fresh water and sediment into the delta marshes. Engineering projects designed to maintain navigation on the Mississippi River confine water flow to deep, straight channels, forcing the sediment-laden water to bypass the wetlands and deposit its silt into deeper Gulf of Mexico waters. Humanmade channels, built through the wetlands for navigation and for easy access to off-shore oil rigs, increase the encroachment of salt water into interior wetlands, killing the salt-intolerant vegetation and accelerating the loss of organic matter and the conversion of wetlands to open water. Wave action from boats traveling along the channels accelerates the erosion of the shorelines.

The more rapid sealevel rise predicted with climate change, combined with continuing subsidence, will further increase the rate and extent of wetland loss. Commercial fishers may actually see an initial increase in their harvests and profits. Shrimp production may increase rapidly during the early stages of wetland decline as open-water habitat increases, as marshes fragment, and as organic matter is released quickly by decaying vegetation, providing food sources for aquatic organisms. However, the initial boost of productivity will likely be followed by a long and potentially rapid decline. if sea level changes rapidly, some commercial fisheries may be lost entirely (see box 2-C).

What can be done to slow the loss? Many scientists who study wetlands view engineering activities with suspicion because they have been the cause of past damage. However, further engineering maybe necessary to reverse the damage that has already been done. The Army Corps of Engineers has already experimented with various techniques for offsetting the losses, and it should continue to evaluate their effectiveness to determine whether they should be implemented more widely. The techniques include: 1) implementing projects to divert fresh water to maintain the proper salinity, and to divert sediment to inhibit subsidence and to help create new wetlands in shallow open water; 2) backfilling and plugging certain dredged canals to prevent saltwater intrusion; 3) establishing salt-tolerant vegetation in areas where the natural vegetation is threatened by salt water; 4) effectively using maintenance dredge materials to restore proper marsh elevations for wetland vegetation; 5) improving management of water levels and salinities by using levees and water-control structures to preserve and enhance existing wetlands and to restore degraded wetlands; 6) restoring wetlands drained for grazing purposes; and 7) reducing the widespread use of forced drainage of wetland areas, thereby reducing sediment compaction and subsidence. Although levees and water-control structures are useful for controlling water level and salinity, they prevent or restrict the mobility of aquatic organisms, and interfere with hydrology and sedimentation patterns-the very reason why Louisiana marshes, and some others, are so degraded today, and also why the Mississippi River appears to have reclaimed its floodplain.

SOURCES: Louisiana Wetlands Protection Panel (LWPP), Saving *Louisiana's Coastal Wetlands: The* *Need for a Long-Term Plan of Action,* EPA-230-02-87-026, report of a panel convened by U.S. Environmental Protection Agency (EPA) and Louisiana Geological Survey at Grand Terre Island, LA, Sept. 17-19,1985 (Washington, DC: U.S. EPA, April 1987); J. McPhee, The *Control of Nature (New York:* Farrar, Straus, Giroux, 1989); U.S. Department of the Interior (001), Fish and Wildlife Service (FWS), Wetlands: Meeting the President's Challenge---1990 Wetlands Action Plan (Washington, DC: U.S. DOI, U.S. FWS, 1990); V. Van Sickle-Burkett et al., National Wetlands Research Center, U.S. Fish and Wildlife Service, tables describing coastal wetland vulnerabilities to climate change, prepared for U.S. Office of Technology Assessment, May 1992.

Box 4-G-How Could Climate Change Affect Wetlands?

Temperature---Increased air temperatures may speed evaporation of surface water from wetlands (and from runoff and water bodies that supply wetlands) and could increase the rate at which wetland plants lose water through evaporation and transpiration if the warmer temperatures are not accompanied by increased rainfall. Drying is most likely to occur at the edges of wetlands and could reduce the size or extent of inland wetlands. Warmer temperatures will increase the rates at which plants decompose, affecting the amount of organic material buried on the marsh floor. Warming could also increase the frequency and severity of drought and fires in seasonal wetlands, which could lead to major changes in and loss of vegetation and habitat. Warming in tundra areas could thaw the upper layer of the permafrost, making it more susceptible to drying, and could lead to significant reductions in the areas of both arctic *and alpine* tundra (120). Changes in the diurnal and seasonal distribution of temperature (such as warmer nights during winter and earlier spring thaws) will affect whether **and,** if so, how wetlands benefit from warmer temperatures. For example, mangroves may expand northward, replacing brackish marshes on the northern coast of Florida and throughout the Gulf of Mexico wherever frosts and freezes become less frequent. Warmer temperatures in large bodies of water could boost productivity in the associated wetlands but would affect the mix of species that could thrive,

Precipitation and soil moisture--Hydrology is an Important factor in determining levels of productivity, decomposition, and nutrient cycling in wetlands. Whether precipitation increases or decreases, ail of these functions will be affected. Shifts in hydrological effects may develop in a stepwise manner, with new climate patterns first affecting current vegetation (through shifts in soil moisture), then plant cover, and finally the permeability of soils. Alterations of plant cover and soil permeability may then act in a feedback loop to further modify the hydrological cycle.

Increases in precipitation may cause shifts in vegetation but are not likely to cause as much disturbance to wetlands as are drier conditions. In fact, increased precipitation along the Atlantic coastal plain, which is predicted by some models (64), could benefit Atlantic coast wetlands by transporting increased sediment from upstream to coastal areas, and by maintaining high freshwater flows to help offset saltwater intrusion-both of which may help lessen the potential destruction of coastal wetlands by sea level rise.

Reduced precipitation is more likely to be harmful than is increased precipitation, especially in semiarid or water-limited regions, leading to reduced riparian areas and desertification on semiarid flatlands. A drier continental interior, predicted by many climate models (49, 64; see also ch. 2), will mean less water and sediments moving down the Mississippi River and even greater problems for the coastal swamps and marshes of the Mississippi River Delta. It will also likely exacerbate problems associated with saltwater intrusion up the Columbia River and rivers associated with estuaries such as Puget Sound, San Francisco Bay, and the Tijuana River. Throughout estuarine and coastal systems, lower precipitation will exacerbate ail the impacts and problems associated with sea Ievel rise.

Increased carbon dioxide (CO_2)--Concentrations of atmospheric $C0_2$ are expected to reach twice the pre-industrial concentration (around 275 ppm) by the middle of the next century (49). The effects of this change on the productivity and composition of natural plant communities, including those in wetlands, are difficult to predict. The fertilizing effect of elevated CO_2 concentrations has been shown to boost productivity in Chesapeake Bay salt marshes (5, 26,27, 130), but the effect does not appear to occur for sustained periods in arctic tundra (44, 72), and other types of wetlands have yet to be tested for the effect. Some of the best long-term, open-environment experiments on the effects of increased $C0_2$ have been done on tidal wetlands. These studies do not provide definitive answers but suggest that elevated $C0_2$ concentrations tend to favor C_3 species over plants using the C_4 pathway for photosynthesis (see ch. 2 for a discussion of C_3 and C_4 plants). Most coastal wetland grasses are C_4 plants, whereas most sedges, rushes, forbs, and the weedy grass **Phragmites** ***australis*** ***are C_3 plants, as*** **are all** mangrove species. With rising CO_2, therefore, the C_3 species, which now tend to ***be***

(Continued on next page)

Box H-How Could Climate Change Affect Wetlands?--(Continued)

relatively less abundant, especially in more saline areas, may tend to become more important members of the plant community of the salt marsh--but the magnitude of this change and its effects on salt marsh functions are impossible to predict.

Accelerating sea level rise--Sea level has been rising at a gradual rate of 4 inches (10 centimeters)[1] per century for the past 3,000 years. At this rate, intertidal low marshes were able to accrete sedimentsts and produce peat at a rate that allowed the vertical marsh growth to keep up with or exceed the sea level rise. Behind the intertidal zone, marsh surface elevations rose **above** mean high tide, creating anew "high-marsh" niche flooded only by spring tides, where marsh vegetation could grow. As sea level rises, high-marsh vegetation moves landward, over the gradually submerging uplands. For a particular marsh to survive in the face of rising sea level requires-at a minimum--room for landward expansion as well as sufficient sediments to support a rate of surface accretion that on average, tracks the sea level rise. The extent of sea level rise expected to occur with thermal expansion of the oceans due to global warming--5 to 11 inches by 2050---may exceed the ability of tidal wetlands to accrete sediments and produce roots fast enough to keep up with the rising **sea level.** Vegetation may change and productivity may decrease; in some areas, wetlands maybe converted to open water.

In addition to the possibility that a rising sea may inundate coastal wetlands, it may also increase the distance that salt water intrudes into estuaries, rivers, and even coastal aquifers. Saltwater intrusion may be magnified if precipitation within a watershed decreases at the same time that sea level increases, or if upstream water withdrawals for human use reduce water flows. Saltwater intrusion could affect brackish and fresh tidal wetlands and freshwater coastal swamps, either converting thereto salt marsh or damaging vegetation **enough that those** areas are converted to open water.

1 To convert inches to centimeters, multiply by 2.540.

SOURCE: Office of Technology Assessment, 1993.

along the lowest-lying coasts may begin to change (i.e., become larger or disappear) as they are inundated.

While some wetlands may lose species and area because of either increased drying or inundation associated with climate change, others could prosper or expand. For example, the fertilizing effect of elevated CO_2 concentrations (described in ch. 2) boosts productivity in Chesapeake Bay salt marshes (5, 26, 27, 130). However, the fertilization effect does not appear to extend to tundra (44, 72). The extent of the fertilization effect in other wetland types has yet to be tested. In many cases, land use in adjacent areas will be a determiningg factor in whether any benefits can be realized. Wetlands buffered by undeveloped natural areas may have room to move and grow, whereas wetlands in areas where land is fragmented among many competing uses will be less likely to benefit. Wetland expansion might be accompanied by changes in vegetation, which could alter the products of, and the functions currently performed by, a given wetland.

Even where climate change benefits wetlands, however, expansion of wetlands in one region will not necessarily compensate for reductions in distant or dissimilar wetlands because the functions and values differ so widely. For example, in part of the Southeast, rainfall is predicted to increase enough to compensate for higher evaporation rates as the temperature warms, so parts of the region may become wetter. Riparian areas and bottomland hardwood wetlands could expand under these conditions. At the same time, vast areas of arctic tundra may be at risk as warming in the upper latitudes allows the permafrost underlying the wetlands to melt and drain (described in more detail below). Gains in southeast-

Table 4-I—Wetland Vulnerabilities to Climate Change

Wetland type	Vulnerability	Key climate factor, functions at risk
Coastal salt marshes	High	Sea level rise and coastal erosion from storm surges could inundate these areas faster than they can migrate At risk fish, shellfish, flood and *erosion control, habitat*
Mangrove swamps	Medium	Increased winter temperatures could favor growth, but sea-level rise, storm surges, and saltwater intrusion could cause net reduction *At risk* fish, *shellfish, habitat, flood and erosion control*
Tidal freshwater marshes	High	Decreased precipitation (lower water flow in rivers entering estuaries) combined with sea level rise could diminish or convert to salt marshes or open water *At risk fish, shellfish, flood and erosion control, habitat*
Inland freshwater marshes (including prairie potholes)	High	Increased temperatures, decreased precipitation could dry out shallower marshes such as prairie potholes *At risk key migratory bird breeding grounds*
Inland saline marshes	Medium to high	Increased temperatures, decreased precipitation could dry out shallower fringes At risk: *waterfowl and wildlife habitat.*
Bogs	Low to medium	In the Southeast, a wetter climate could aid bogs In the Northeast and Midwest, decreased precipitation could further degrade contaminated bogs *At risk: cranberries, blueberries, water quality*
Tundra	High	Warmer temperatures in alpine and arctic zones could melt **and dry permafrost** *At risk key source of carbon storage, wildlife habitat*
Shrub swamps	Low to medium	Higher precipitation in the Southeast could allow for expansion, lower precipitation in the Midwest would diminish the fringe areas, *At risk flood and erosion control, water quahty, habitat*
Wooded swamps	Low to medium	Higher precipitation in the Southeast could allow for expansion; lower precipitation in the Midwest would diminish the fringe areas *At risk: flood and erosion control, water qua/@, habitat.*
Bottom lands and other riparian habitat	High (in the Southwest)	Increased temperatures, lowered precipitation and runoff would reduce riparian habitat in the arid Southwest. At risk *fish and wildlife habitat, flood and erosion control, water quality, grazing*

SOURCE: Office of Technology Assessment, 1993 (adapted from Office of Technology Assessment Wetlands Advisory Panel Workshop, May 1992)

Box4-H--Will Climate Change Increase Conflicts Over Riparian Wetlands in the Arid West?

Like cases in the desert, riparian wetlands in the arid West offer lush vegetation and cool shade, presenting a respite from the hot sun and dry climate that attracts humans as well as wildlife. Riparian areas occupy just 1 percent of the arid lands in the West, but provide food and habitat for three-quarters of the wildlife species in those areas, including half of ail bird and vertebrate spades in the region (40, 103, 104). Rafting, fishing, **and canoeing** on western rivers **and streams make** an enormous contribution to local economies in the West. The river-outfitting industry in Colorado alone generates $70 million annually (77). Riverside and streambed wetlands are valued by ranchers as a haven for cattle, which seek out the cool shade of cottonwood and willow **and the** high-quality forage. After heavy rains, riparian vegetation filters sediment from runoff water, helping to build and maintain stream banks, protecting against erosion, and offering a buffer against floods. Riparian wetlands even play an important role in how a watershed functions: the vegetation shields water and soil from the sun, slowing evaporation (19).

Yet despite their many functions, riparian wetlands are under constant threat, even In the existing climate. As wet areas in a landscape where water is scarce, they are often overused. The Environmental Protection Agency (EPA) estimates that overgrazing has been the most geographically extensive cause of riparian wetland degradation and loss (15). Overgrazing, either by too many animals or for too long a period of time, prevents new plants from taking root and holding down the soil. As a result, stream banks erode, channels become shallow and laden with sediments, water quality and quantity decrease, and, eventually, the stream may flow only intermittently or not at all. Riparian wetlands may also be destroyed by the destructive Iand-clearing practices associated with mining and logging. Removing vegetation often leads to erosion that washes sediment into rivers and streams, filling wetlands and allowing them to dry up.

Even more threatening to riparian areas has been the diversion of water from rivers and streams for competing uses, either by direct pumping or by projects designed to **channel the water.** Water rights are hotly contested in many parts of the West, with water from many rivers already allocated in greater amounts than normally flow, and the need for water to remain instream (i.e., in the river rather than pumped out or directed) for fish, wildlife, and wetlands is not always recognized. Farmers channel or pump from streams to fields for agricultural use, while cities siphon off water for drinking and other purposes. These water diversions leave less water for riparian areas downstream, and because riparian vegetation depends more on flowing water than on precipitation, Iess water in the stream bed translates to Iess or even totally lost vegetation (28, 38). All told, more than 80 percent of riparian wetlands have been destroyed by human activity, with an associated loss of habitat and decline of wildlife populations (40, 51, 117).

Climate change could impose greater water stress on already-degraded wetlands, both from lower precipitation and from ever-increasing competition with human activities. Climate models predict that conditions will be hotter and drier in the already-arid West (49). A warmer climate may bring rain rather than snow in the winter, allowing precipitation to run off immediately rather than to remain in snowpacks that melt in spring as the growing season begins. The earlier runoff could mean that drier conditions would start earlier in the year, making summer **and fall water shortage and quality** problems worse in many parts **of** the West (84). As water becomes more scarce, the competition and potential conflicts over water use could increase. Drought-stricken farmers and expanding cities alike may demand more water development projects to makeup for lower precipitation, and ranchers may be more inclined to encourage grazing in riparian areas (or demand grazing rights on publicly owned properties) as surrounding rangelands decline. Riparian wetlands, along with the fish and wildlife that inhabit them, may well lose out among the competing demands and decreasing water flows.

Although most riparian wetlands are protected from the physical disturbances of dredge and fill activities (Section 404 of the Clean Water Act (P.L. 92-500)), they receive little legal protection against the upstream water diversions that might ultimately cause their destruction. Some fish and wildlife agencies and other conservation groups have recently begun to purchase water rights for instream flows to protect riparian wetlands and wildlife, including fish. In the West, however, water is allocated according to the prior appropriation doctrine, which gives priority to those who first diverted water from a river and put it to use--"first in time, first in right." (See vol. 1, ch. 5.) In most cases, the water rights purchased for natural areas are "junior" to those owned by farmers and cities, so in a water crisis, water for natural areas would be among the first to be lost. The Wild and Scenic Rivers Act (P.L. 90-542) protects instream flows for certain designated rivers, but water rights for National Parks and wilderness areas have yet to be claimed by the Federal Government. Even these protections, which are already controversial, may become more so as water becomes more since.

SOURCES: E. Chancy, W. Elmore, and W.S, Platts, L/vestal Grazing on Western Riparian Areas, report prepared for the U. S. Environmental Protection Agency (Eagle, ID: Northwest Resources Information Center, Inc., 1990); U.S. Department of the Interior, Bureau of land Management, *Riparian-Wetland Initiative for* the 1900'S, BLM/WO/GI-91/001-4340 (Washington, DC: Bureau of Land Management, September 1991); U.S. General Accounting Office, Range/and *Management: Forest Service* Not *Performing Needed Monitoring of Grazing Allotments,* GAO/RCED-91-148 (Washington, DC: General Accounting Office, May 1991).

ern wetlands could not compensate for the loss of habitat and carbon storage provided by arctic tundra wetlands. Likewise, expansion of inland wetlands within a coastal watershed as sea level rises may be important to the estuary, but those wetlands would not perform the same nursery functions for fish and shellfish as do the wetlands right at the coast. Regardless of the benefits, then, climate change may still pose a threat to many functions and products of wetlands.

Although climate change may affect wetlands directly, many scientists and policy makers consider the activities currently degrading and destroying wetlands-agriculture, development, pollution, and changing water and sediment flows—to be the biggest threats to wetlands and their economically important functions in the future. Climate change would add to the stresses posed by these activities: a decrease in runoff in the Northeast could worsen water quality; competition with urban and industrial water uses would probably reduce the water available for wetlands; and increased pressure for water diversions might further alter water and sediment flows to wetlands (84). Thus, in many areas, the direct effects of climate change may not overtake existing sources of degradation and loss as the dominant threat to wetlands in the near term, but will likely exacerbate current trends of loss and degradation.

Because the United States has already lost more than half of the wetlands it contained 200 years ago (over 100 million acres), the potential for climate change to spur further losses and degradation could pose a significant threat to valued functions of wetlands (103). If losses continue at current rates, FWS estimates, the Nation may lose another 4 percent (approximately 4 million acres) of remaining wetlands in the conterminous States by the year 2000--and this estimate does not account for any additional losses in area or function due to climate change (108). Losses of inland wetlands will likely continue to make up the bulk of total losses of wetlands because that is where most U.S. wetlands lie, but coastal wetlands may suffer larger proportional losses in a changing climate because of the threat posed by a rising sea level.

B Can Wetland Species Adapt to Climate Change?

No single factor determines whether the various plant and animal species that make up a wetland can adapt to climate change or whether a particular wetland system will lose some or all of its functions and products. In any given site, wetland species may respond in three interrelated ways as the environment changes around them: they may change, migrate, or decline. Which response prevails will depend on where a wetland lies in the landscape, its size, its hydrology, the health of its vegetation, and other physical, biological, and anthropogenic factors that have shaped it over time, combined with the rates at which regional patterns of temperature, precipitation, and evaporation change.

Change

Depending on the rate and magnitude of climate change, wetlands and the species that inhabit them may adapt to new climate conditions. New plants may become dominant, and different animal species may be associated with them (66). In a given wetland, a moderate change in precipitation may induce a gradual change in plant species composition but cause little harm to wildlife habitat, recreational use, or floodplain protection. A greater change might convert a year-round wetland into a, seasonal one, affecting vegetation and impairing wildlife habitat and recreational value, but perhaps allowing continued floodplain protection.

Migration

Wetland vegetative species may migrate to surrounding, similar areas if such areas exist and if migration pathways are not blocked by topographical or anthropogenic barriers. For example, coastal and estuarine wetland vegetation will begin to take root further inland as the sea level rises. Whether the vegetation becomes established successfully will depend on the rate at which water levels rise, the steepness of the coast, and the presence of barriers, such as rocky areas and human-built structures. Wetlands fringing the playa lakes of the Southwest may retreat or become degraded along the water line if increased evaporation in a hotter and drier climate causes water levels to drop, and farmers may then till up to or through the fringe. In many areas, adjacent human activity severely limits the ability of wetlands to move or flourish.

The likelihood of successful migration will differ for coastal and inland wetlands. In coastal areas, vegetation attempting to take root upslope of the rising sea may face competition from plants already in place that have well-established root systems and that may not give way easily. In inland areas where drying and drought occur, plants attempting to move downslope to follow declining water levels in rivers or depressions will not likely face the same kind of competition; the submerged plants that might have competed will likely die when the water recedes. In both coastal and inland areas where channels have been dug, however, migration will be difficult or impossible because the sharp slope at the channel's edge may present an insurmountable barrier.

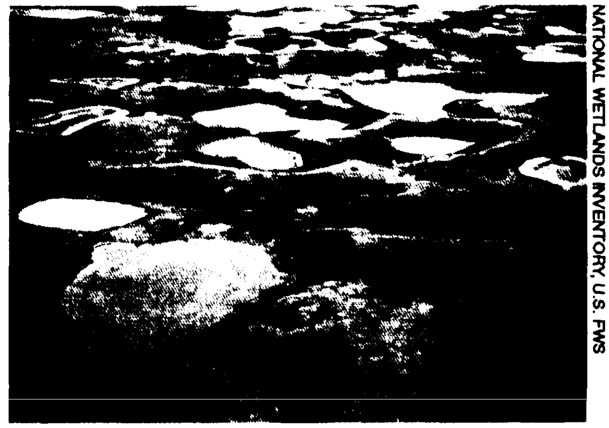
Even where room to grow is available, there are limits to migration. As noted in chapter 2, it is unlikely that entire assemblages of plants and animals can simply pick up and move together in lockstep. Some species will migrate quickly, others slowly, others not at all. Patterns of competition and predation may be significantly altered, affecting which species will survive migration. Long-term studies of degraded or damaged wetlands suggest that change may take place slowly, one species at a time, and that not all species recover.[8] Random events, such as weather and chance dispersal of seeds, affect the probabilities of migration and survival, Any migration may be accompanied by a loss of biodiversity along with the loss of some of the wetland's functions and products.

Decline

Wetlands in some sites may disappear entirely or become so severely degraded that they lose the functions and products by which they are now characterized. If climate change is rapid or severe, some wetland species may not be able to adapt. Coastal wetlands not degraded by human activities have kept pace with a sea level rise of

[8] B. Bedford, Director, Association of Ecosystem Research Centers, and Professor of Ecology, Cornell University, personal communication, Nov. 4.1991.

approximately 0.04 inch (1 millimeter) per year (the rate at which many marshes are able to accumulate material) for the past 3,000 years, but at significantly faster rates, they would drown (114). Likewise, alpine and arctic tundra wetlands may shrink and, in some sites, disappear if the amount and speed of climate change are too great. The ability of many wetlands to survive has been diminished by land-use patterns that have fragmented or degraded them so much that they have little capacity to migrate or evolve.



Prairie potholes such as these in the Lostwood National Wildlife Refuge, North Dakota, are scattered throughout the Midwest (North Dakota, South Dakota, Montana, Iowa, and Minnesota). They have been subjected to increased drainage due to agricultural demands, yet they serve as prime habitat for nesting waterfowl, and support countless other species as well.

Which Wetlands Are Vulnerable to Climate Change?

Some wetlands may continue to perform their most valued functions even if they are degraded by climate change. For example, changes in habitat quality in an urban wetland might not be considered a particularly large impact. On the other hand, maintenance of the flood-control function may be considered vital. Thus, as long as some vegetated areas remain to slow incoming flood waters, the valued functions of this wetland might not be considered vulnerable to climate change. If coastal wetlands decline, however, many of their important functions, including providing habitat for fish and buffering the shoreline, may suffer. Although both functions could to some extent be replaced by artificial constructs (e.g., fish hatcheries and ponds could be created to produce fish commercially), such measures would incur large and continuing costs and would involve other tradeoffs. These measures could not replace such functions as nurturing biodiversity and providing recreational opportunities. Thus, coastal wetlands might be considered vulnerable because they cannot easily adapt to sea level rise and because many of the functions and products that they provide are threatened.

Overall, four types of wetlands are likely to face difficulties in adapting to climate change and can thus be considered highly vulnerable: 1) coastal wetlands, 2) depressional wetlands in arid or semiarid areas (i.e., prairie potholes in the North Central States and vernal pools in California), 3) riparian wetlands in the arid West and Southwest, and 4) tundra wetlands (see table 4-l). *Coastal and estuarine wetlands maybe* drowned by a rising sea or altered by the changing salinity levels. *Depressional wetlands are* susceptible to the lowered water tables that will likely result from the higher temperatures, increased evaporation, and decreased summertime precipitation predicted for these already arid or semiarid areas. *Riparian wetlands in the* arid West, which rely on water flowing through rivers and streams, could also be threatened by drier conditions and increased competition for water. *Tundra* may shrink as increased temperatures allow the permafrost to thaw and drain. In addition, wetlands of any type that are already degraded by pollution, water diversions, or fragmentation may be particularly vulnerable (119, 123). These vulnerabilities are described in more detail below.

Coastal *Wetlands*

Accelerated sea level rise combined with tropical storms (even if storm frequency does not increase) will exacerbate "the current losses of coastal wetlands. Wetlands along the low-lying coasts of the Southeast, from North Carolina in the Atlantic to Texas in the Gulf of Mexico, are already subsiding due to *compaction* (i.e., compression of estuarine or deltaic sediments by new layers of sedimentary deposits). These areas may be either flooded or washed away as prevailing water levels rise (see ch. 2). Lands in the Mississippi River Delta are expected to suffer the highest rates of coastal erosion and loss of wetlands (see vol. 1, ch. 4). Indeed, erosion of coastal wetlands is already proceeding rapidly in Louisiana, and increasing rates of loss are expected with accelerated sea level rise (see box 4-F). Approximately half of the 5.5 million acres of coastal wetlands that remain in the United States are found along the Gulf of Mexico (16), making the potential for loss great.

Accelerated sea level rise will also be accompanied by *saltwater intrusion*-that is, salt water moving inland into estuaries and rivers-which may further alter or destroy coastal wetlands that depend on fresh water or a balance of fresh and salt water (see vol. 1, chs. 4 and 5, for further discussion). This effect may be especially damaging to tidal freshwater wetlands that lie near the upper reaches of tides in many coastal rivers. The higher and rockier coasts bordering the North Atlantic and Pacific Oceans are less likely to experience losses of wetlands, in part because these rocky coasts harbor fewer to begin with. However, some important estuarine systems in these areas, including Puget Sound, San Francisco Bay, and Tijuana Estuary, may be highly vulnerable because of local subsidence, erosion, and water diversions that have dramatically altered water and sediment flows. Each of these areas has already lost many wetlands to water diversion and competing land uses. Further losses might irreparably harm the already-diminished functions and products (83, 126).[9]

The key to whether coastal wetlands will be able to adapt to climate change is migration--the ability to move inland to keep pace with the rising sea (114) (see vol. 1, ch. 4). Although topography, geology, and the coast-shaping processes that accompany storms are important limiting factors to migration, human responses to sea level rise will perhaps be even more important. Societal measures taken to protect the coasts will help determine the pattern and rate of loss; such measures could range from no additional protection (which is unlikely in developed areas) to efforts to protect not only major coastal developments but more rural areas as well. Wetlands along highly developed coasts, including much of the Atlantic coast from Maryland to Massachusetts, may become quite vulnerable to climate change because control structures such as sea walls and bulkheads already form barriers to migration. As the sea level rises, the public may desire to take even more aggressive measures, such as constructing dikes, to protect human life and property values in densely settled areas. Even along undeveloped coasts, the land just above sea level into which wetlands could migrate is generally smaller than the area of wetlands at risk from climate change (91). Thus, coastal wetlands may simply be squeezed out between the rising sea and the flood-control structures that are already in place or that may be constructed to protect coastal properties.

Several functions and products are at risk if coastal wetlands are diminished and altered by climate change. In ecological terms, Atlantic tidal marshes are remarkably homogeneous in species composition from Florida to Maine, so it may appear that some losses will not pose a significant threat to overall fictions and products. However, regional populations of many species have developed adaptive characteristics that may not be common in the species as a whole, so declines in any region still reduce the genetic diversity

[9] D. J. Canning, Shorelands and Coastal Zone Management Program, Washington State Department Of Ecology, personal communication, Nov. 11, 1992.

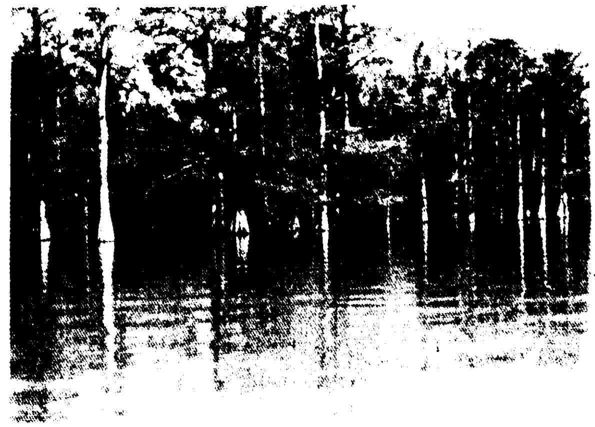
within individual species. Furthermore, some fish populations spawn and feed in specific estuaries; significant losses in one estuary could have large ripple effects on the fishery as a whole.

Coastal wetlands play a vital part in supporting the commercial fish and shellfish industries. Nationwide, estuarine wetlands provide essential food and habitat for three-quarters of the commercial catch of fish and shellfish, valued at $5.5 billion per year dockside, not counting the value added from processing (see box 4-D). The shrimp harvest in Louisiana alone is worth some $100 million. Degradation and destruction of coastal wetlands due to sea level rise may initially boost the production of fish and shellfish. However, the near-term productivity boost may be followed by a longer-term decline if new vegetation cannot take root and survive. The potential impacts on the fish and shellfish industries and the people who rely on them for jobs and livelihood could be substantial (see box 4-F) (64, 113, 129). In the Chesapeake Bay, landings of migratory fish species, including shad, herring, and bass, declined 66 to 96 percent from the mid- 1960s through the mid- 1980s. Oyster harvests declined 96 percent in the past century, and the bay has lost half its wetlands, including 90 percent of all its seagrass meadows, which form prime nursery habitat. Although many other factors, including pollution and overfishing, have contributed to this decline, the loss of habitat in wetlands is considered to be a primary cause (14, 16).

Loss of coastal wetlands will also reduce their capacity to control floods, reduce shoreline erosion, and filter pollution from runoff water as it passes from land to sea. The costs of these losses in function are hard to quanttify and are intricately related to other coastal issues (see vol. 1, ch. 4).

Depressional Wetlands

Shallow depressional wetlands in arid and semiarid parts of the West (including the prairie potholes of the Great Plains; the *playas,* flats, and



Southern bottomland hardwood wetlands-this one in the Lower Mississippi Alluvial Plain--are one of the Nation's most important and most at-risk resources. They are home to millions of migratory birds and countless other species of wildlife, and they play vital roles in controlling floods and in maintaining water quality.

rainwater-basin wetlands of Utah, Nevada, Nebraska, Kansas, Oklahoma, and Texas; and the vernal pools of California) are particularly vulnerable to hotter, drier conditions. Most depressional wetlands are oases of habitat for birds and wildlife in the midst of an otherwise dry landscape. Some form important feeding grounds for waterfowl that migrate from Canada to the Gulf of Mexico, whereas others provide year-round habitat for numerous wildlife species. California's vernal pools are particularly valuable as habitat for several endangered species (128). The prairie-pothole region is valued for the recreational opportunities it provides to hunters and bird-watchers (see box l-F).

Higher temperatures and increasing frequency or severity of drought will speed evaporation and lower water levels in these wetlands or reduce the time during which they remain wet. These alterations in the water regime could cause extensive changes in vegetation, and reduce the quantity and quality of food and habitat for migratory waterfowl (6).[10] Larger wetlands are likely to

[10] K, A. Pioani, Ecosystems Research Center, Cornell University, personal communication, November 1992.

better withstand the effects of drying and maintain the range of diverse habitat conditions that will continue to support a wide range of species. Smaller ones will change the most under warmer and drier conditions; as they become shallower, they will become choked with cattails and other cover plants that will leave less open water for waterfowl breeding. In addition, some smaller wetlands may convert from year-round to seasonal wetlands, which would significantly change their use as habitat. Spring precipitation maybe one of the most important factors in determining the degree to which smaller and semipermanent depressional wetlands are affected by drier conditions.[11]

Protection of prairie potholes was the impetus for the passage of the Migratory Bird Hunting and Conservation Stamp Act in 1937 (P.L. 94-215), which levied fees on hunters to support the purchase of some pothole areas; these purchases signaled the start of a national system of wildlife refuges (see ch. 5). Numerous laws and land acquisitions since then have sought to protect the wildlife and recreational values of the prairie-pothole region. However, competition for land and water resources may further increase under climate change, particularly if climate change leads to expansion of agriculture in the region (see vol. 1, ch. 6).

The ability of western depressional wetlands to sustain waterfowl and other species that rely on them during climate change will depend in large part on the Nation's success in protecting them against other threats and restoring areas that have already been damaged. The key to maintaining depressional wetlands throughout the arid West will be to conserve water to help maintain water tables at their present levels, to find supplemental supplies where possible, and to restore degraded or drained wetlands where possible. Other possible conservation strategies include maintaining existing wetlands, increasing protection of deeper areas that may provide better habitat and are more likely to persist in dry years, and coordinating protection of wetlands within regions so that if some are lost others in the general vicinity may remain.

Western Riparlan Wetlands

Riparian areas in the arid West are also highly vulnerable to the hotter and drier conditions predicted for much of the interior West. Predicted increases in temperatures and evaporation rates in this region, combined with reduced rainfall during the growing season, could greatly reduce the runoff entering streams and rivers. Some small or seasonal streams and their associated wetlands could disappear altogether.

Riparian wetlands in the West are highly valued for the habitat they provide to waterfowl, fish, and wildlife. Those habitats now comprise less than 1 percent of the western landscape, yet they support a vast recreational industry including hunting, fishing, and boating. Riparian wetlands are often the only forested areas in western flatlands, and they are critical for breeding, hunting, and cover for many mammal and bird species that inhabit these areas. They offer lush grazing grounds for deer and other wildlife and range-fed cattle. USDA estimates that over 80 percent of riparian habitat has been lost due to grazing and diverting water for irrigation and municipal uses (98). Climate change and increasing competition for scarce water resources could accelerate the loss of riparian habitat and could lead to diminished wildlife and fish populations, degraded rangeland, and reduced recreational values.[12] The potential for conflicts among different uses of riparian land and water is discussed in more detail in box 4-H.

Like coastal wetlands, riparian wetlands have some capacity to adapt to a changing climate by migrating along river edges up- and downstream

11 Ibid.

12 C. Segelquist, U.S. Fish and Wildlife Service, National Ecology Research Center, Riparian and Wetland Ecology Project, personal communicator July 15, 1992.

as well as up- and down-slope to follow the water. However, in those areas subject to hotter and drier conditions, rivers are likely to shrink, so migration will likely involve retreat rather than expansion.

Tundra

Alpine and arctic tundra peat lands with water-saturated soils are highly vulnerable to climate change. Warmer temperatures will allow the permafrost layer, on which tundra relies for sustaining moisture, to thaw and drain.[13] As the upper layers of permafrost dry, the tundra vegetation and soils will start to decompose, releasing stored carbon into the air and potentially adding to the feedbacks that spur global warming (see ch. 2). Permafrost melting and decomposition of tundra soils may also cause the surface to subside, which could affect the stability of roads and pipelines built on tundra. Where arctic tundra is situated near the coast, these processes may also lead to increased loss of coastal land as frozen peat melts and slumps into the sea.

Because tundra serves important and diverse functions, its economic value is difficult to judge (see box 4-D). Along with the other northern soils, the tundra sequesters approximately one-fifth of the world's total soil carbon (44, 72, 80). Arctic tundra provides critical habitat and breeding grounds for migratory waterfowl, including certain geese, swans, and ducks, some of which migrate to the Arctic from as far away as the Southern Hemisphere. Organic matter from tundra peat is an important food source for fresh- and saltwater fisheries. In Alaska, arctic tundra provides habitat for the caribou, wolves, foxes, and waterfowl that contribute to the subsistence of the indigenous human population (see ch. 1, box l-G).

Alpine and arctic tundra both have limited capacity to adapt to climate change. As temperatures warm, alpine tundra is likely to shrink as lower-altitude and lower-latitude edges dry. Species now found in alpine and arctic tundra are unlikely to adapt easily in dry areas where the permafrost has been the primary means of maintaining moisture. As soon is it becomes warmer, it will become drier, and the tundra vegetation will decline. Although large areas of relatively pristine arctic wetlands remain protected by their isolation from many of the activities that have harmed wetlands in the rest of the Nation, this does not make them less vulnerable to the risks and impacts of climate change. Few policies other than successful efforts to slow greenhouse warming are likely to stem the loss.

POLICY CONTEXT

The Challenge for Policy

Since 1989, the Federal Government has embraced the policy goal of no net loss of wetlands, but steps to achieve it have not been fully implemented. The impetus for a no-net-loss policy arose from the widespread perception that historical losses of wetlands due to human activities have reduced the ability of remaining wetlands to provide the numerous functions and products for which they are valued, and that further losses would threaten the integrity of wetlands and the larger ecological systems in which they are found. A policy aimed at achieving net gains, promoted initially in 1987 by the National Wetlands Policy Forum (NWPF), received further endorsement in 1992 from the National Research Council (NRC), the policy-research branch of the National Academy of Sciences (NAS), which

[13] In tundra systems, permafrost acts as an impermeable layer between water on the soil surface (the active zone, where vegetation grows during brief Summer thaws) and the soil layers below. When the permafrost melts, the barrier is broken, and water from the surface can then seep into the lower layers, causing the active zone to drain and dry. Drying will likely be most severe in "cold desert' areas of tundra, where precipitation is scarce but moisture has accumulated in the active zone over thousands of years because it was prevented from draining. Not all tundra has accumulated enough moisture to support wetlands, but in areas that do have peat wetlands, those with a relatively thin permafrost layer may be most vulnerable to climate change.

recommended that 10 million acres of wetlands be restored by 2010 (68).

The no-net-loss policy does not prohibit some loss of wetlands to development or other uses if that loss cannot be avoided. What it does seek to ensure is that the overall quantity and quality of wetlands will remain stable. Efforts to restore and create wetlands must be undertaken on some sites to compensate for degradation and losses elsewhere (88).

Climate change may make it more difficult to halt the loss of wetlands and safeguard the multitude of functions and products they provide. This is particularly true in areas where wetlands are surrounded by development, limiting the areas into which wetland plants and animals can migrate. Changes in climate could cause far--reaching alterations in the complex ecological and hydrological systems that make up wetlands. For example, in the North Central States, increased temperatures and evaporation rates could cause many prairie-pothole wetlands to shrink or disappear, leading to further declines in already-diminished continental waterfowl populations (6). In the arid West, drier conditions combined with increased competition for water for human consumption and agricultural use could diminish the riparian and depressional wetlands (those along rivers and in low-lying areas) that now serve as habitat for diverse flora and fauna (84). Increased evaporation could also diminish water flow through streams and rivers in the Northeast and reduce water levels in the Great Lakes, leading to diminished water quality and eutrophication that could degrade wetlands. Rainfall may increase enough in the Southeast to offset the increased evaporation rates that accompany increased temperatures, potentially expanding the sites where wetland vegetation could grow, but gains may be limited by existing land uses and development. In coastal areas, a 20-inch (0.5-meter)[14] rise in sea level could inundate 35 percent of coastal wetlands nationwide by 2100 (84, 73, 74, 91). These and other changes may pose an enormous challenge for Federal efforts aimed at preventing further loss of wetlands.

Yet the same changes in climate will make maintenance of wetlands all the more important. Along coasts where climate change will likely lead to accelerated sea level rise, healthy wetlands can help control coastal erosion and flooding (see vol. 1, ch. 4). In urban areas, large amounts of water-impermeable paved and built surfaces have lead to an increase in runoff during storms, which could become more frequent in some areas as climate changes. Wetlands may help absorb and slow this runoff and prevent flooding. Wetlands filter water and improve water quality, which may become increasingly important in areas where climate change leads to drier conditions and thus to higher concentrations of pollutants in runoff and surface water (see vol. 1, ch. 5). Habitat provided by wetlands harbors diverse species of fish, waterfowl, invertebrates, and other wildlife; climate change may pose further threats to some species by eliminating habitat in some areas, making the remaining wetlands even more vital to efforts to protect endangered species (see ch. 5).

Wetland Management

Whatever is done to address the problems associated with wetland protection, restoration, and migration, those efforts will be more effective if the Nation addresses the problems caused by fragmentation-both of the landscape (see ch. 5) and of Federal agencies that oversee wetlands. Management decisions affecting wetlands are made by many different agencies, authorized by piecemeal legislation, often with conflicting goals or criteria for decisionmaking. All of the many scientists and managers consulted by the Office of Technology Assessment (OTA) emphasized the need for more integrated, coordinated management, planning, and decisionmaking for wet-

14 To convert inches to meters, multiply by 0.025.

lands. Three aspects of coordination demand attention now:

- clarifying the goals for which wetlands are managed and amending or eliminating Federal programs that conflict with those goals;
- developing and applying a method for identifying which wetlands should receive the highest priority for preservation and restoration within particular watersheds; and
- using approaches that would coordinate management across resources and across watersheds or ecosystems (see ch. 1).

Integrated management should include intensive and broad-based monitoring to assess the rates at which features of wetlands are being affected by climate change, to evaluate the effectiveness of efforts to protect and restore wetlands, and to gauge the impacts of the degradation and loss of wetlands on the functions and products they provide. Monitoring is essential for identifying where limited funds should be directed.

Wetlands cannot be managed effectively in isolation. Many of the functions and products that make wetlands important-wildlife and fisheries habitat, flood control, biodiversity, and so on—depend on the integrity of a broad system of wetlands and water resources. Further, as described above, wetlands within watersheds are often linked by surface- or groundwater flows, so disturbance to one may affect others. For example, water diversions upstream of a wetland can degrade or destroy the wetland's vegetation and habitat quality by altering water and sediment flows, and overuse of groundwater for municipal or agricultural purposes may disturb wetlands throughout a given aquifer.

By considering wetlands along with the range of pressures on other resources, planners and managers can make better decisions about the most ''valuable' areas to be protected and restored in a given region. With the threat of climate change and the possibility that the characteristics of wetlands may change, a coordinated strategy for maintaining the functions and products of wetlands becomes all the more important.

The options presented in this chapter are based on maintaining the national commitment to protect the existing net quantity and quality of wetlands and, where wetlands have severely diminished or been degraded, to restore them. To maintain that commitment in the face of climate change, policy makers should focus on these four objectives, discussed in the following section:

1. Protect remaining wetlands. Mitigate the rate of loss by strengthening the protection and maintenance of existing wetlands, to increase the chances that wetlands will remain in locations from where they can migrate or adapt.
2. Restore what has been lost. Encourage restoration of wetlands to compensate for past and expected future losses.
3. Facilitate adaptive migration. Prepare for and assist in the migration of wetland species, which may be needed under a changing climate and accelerated sea level rise.
4. Improve coordinated management and monitoring.[15] Address the problems Of legal and institutional fragmentation. The absence of clearly stated authority for protecting wetlands, inadequate criteria for decisionmaking and lack of a coordinated effort to monitor and evaluate the quantity and quality of wetlands and the water systems that support them must be evaluated.

The Existing Regulatory Framework Governing Wetlands[16]

Regulation of wetlands has increased over the past two decades with the growing recognition of

15 Coordinated management of wetlands cannot easily be accomplished without also considering management of water supplies (see vol. 1, ch. 5).

16 This section draws heavily on material published in references 95, 108, 112 and on a contract paper prepared for OTA (120).

Tidal marshes are intermittently flooded, depending on tidal movement, and include the splash zone of coastal waters. These areas provide a filtering zone for freshwater systems whose outlets are on the coast. They also provide vital habitat for countless species of migratory birds.

the valuable functions and products they may provide. Wetlands are protected, acquired, managed, and restored under a complex array of Federal and State statutes, regulations, and programs, along with common-law public-trust doctrines, local land-use and zoning laws, actions by private landholders, and an increasing body of case law.

No single agency leads the effort to protect and regulate wetlands, and none has the protection of wetlands as its primary goal. Instead, major wetland programs are distributed among six Federal agencies: the U.S. Army Corps of Engineers (the Corps), the U.S. Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (FWS), USDA's Agricultural Stabilization and Conservation Service (ASCS) and Soil Conservation Service (SCS), and the National Marine Fisheries Service (NMFS) in the National Oceanic and Atmospheric Administration (NOAA). Numerous other Federal agencies, including the National Park Service (NPS), the Bureau of Land Management (BLM), the Forest Service (USFS), NOAA'S Office of Ocean and Coastal Resource Management, and the Department of Defense (for wetlands on military bases and reserves), contribute to some aspect of the protection or management of wetlands.

Wetlands are not subject to any single comprehensive Federal law, but are covered by an amalgam of six statutes that address wetlands directly, more than 19 additional statutes with some impact on wetlands, two Executive Orders, and the various programs and regulations spawned by these statutes and orders. Moreover, approximately 100 bills addressing some aspect of wetlands were introduced in the 102d Congress. In addition, as described briefly below, many States and some municipal areas have enacted laws to protect wetlands; in some cases, these laws may be stricter than the Federal programs.

The major elements of the Federal "policy space'—that is, the existing institutions, legislation, and regulations--are described in detail in box 4-I. These programs can be categorized according to three types of government actions: direct Federal action, including regulation, acquisition, restoration, management, and oversight of wetlands; indirect Federal action that encourages the protection and restoration of wetlands through incentives to private property owners; and coordination and research activities that seek to provide information to managers and promote interaction among these individuals.

Direct Federal Action

Regulation and permitting are perhaps the most visible direct Federal controls on wetlands. The principal authority for Federal regulatory protection of private wetlands derives from the Federal jurisdiction over navigation. Section 404 of the Clean Water Act requires permits for discharges of dredge or fill materials into *navigable waters*, which originally included only those through which boats could travel but have been interpreted more recently to include almost all wetlands. This law gives the Corps and EPA a major role in wetland regulation at the Federal level. Most large-scale construction activities affecting wetlands are regulated under Section

Box 44—The Wetlands Policy Space

Regulatory activities and permitting programs--The Army C orps of Engineers, through Section 10 of the Rivers and Harbors Act of 1899, was given regulation and oversight authority of a permit program covering any dredge **and fill activities affecting navigable waters** in the United States. "Navigable waters" has been broadly defined by the Corps to include coastal and freshwater wetlands,[1] and starting in 1968, the Corps expanded the permit criteria beyond the original assessment of impacts on navigation to include assessments of impacts on fish **and** wildlife, conservation, pollution, aesthetics, ecology, flood-damage protection, recreation, water supply and quality, and others.

Although the Rivers and Harbors Act set forth the original regulatory authority, Section404 of the Federal Water Pollution Control Act (P.L. 92-500) of 1972, as amended by the Clean WaterAct of1977 (P.L. 92-217), has become the principal Federal program that regulates activities in wetlands. Section 404 requires that any landowner proposing to undertake activities that would result in the discharge of dredged material into U.S. waters, including wetlands, must first apply for and obtain a permit from the Corps. The application is reviewed in consultation with Fish and Wildlife Service **(FWS), the** Environmental Protection Agency (ERA), the National Marine Fisheries Service (NMFS), and the State where the activity is to take place. Permit applications are evaluated according to the extent of public and private need for the proposed project, whether alternative locations or less environmentally damaging methods could be used to achieve the stated project goals and result in less environmental impact, and the significance of the environmental impact the project may have.

Despite the Corps' broad interpretation of the extent of waters covered by permit requirements, the purview of the Section 404 program is limited in several ways. Numerous activities are exempted from Section 404 jurisdiction, including normal farming, forestry, ranching activities that do not convert natural wetlands to anew use (e.g., cropland), maintenance of flood-control structures, construction of bridges and dams, **and maintenance of** farm ponds, irrigation systems, and drainage ditches. Other activities fall under "general permits," which authorize activities expected to have minor impacts without the need for individual permits, as long as specified procedures for minimizing impacts are followed. On the basis of these limitations, the General Accounting Office (GAO) estimates that Section 404 "regulates only about 20 percent of the activities that destroy wetlands"(112).

Although States have the opportunity to assume primary responsibility for administering parts of the Section 404 program, only Michigan has done so. Many States are using their authorities under Section 401 to modify or deny Section 404 permits as a way to further protect wetlands under the Clean Water Act

Land acquisition--Federai legislation to acquire wetlands dates back to the Migratory Bird Hunting and Conservation Stamp Act (P.L. 94-215), passed in 1934. The act requires that waterfowl hunters purchase "duck stamps"; proceeds from stamp sales are placed into the Migratory Bird Conservation Fund to be used to acquire habitat for migratory birds. Since the inception of the program, more than $240 million worth of stamps have been

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1 ln1975,theCorps issued regulations defining "navigable waters"to include the following:"coastal waters, **wetlands, mudflats, swamps, and** similar **areas;** freshwater lakes, rivers, **and streams** that are used, were used in thepast, or are susceptible to use to transport interstate commerce, including all tributaries to these waters; Interstate waters; certain specified intrastate waters, the pollution of which would affect interstate commerce; and freshwater wetlands, including marshes, shallows, swamps and similar areas that are contiguous or adjacent to the above described lakes, rivers and streams, and that are periodically inundated and normally characterized by the prevalence of **vegetation** that requires saturated **soil** conditions for growth and reproduction" (34).

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Box 44-The Wetlands Policy Space--(Continued)

sold and 2.5 million acres (about 1 million hectares)[2] of habitat purchased Although some habitat purchases have been upland nesting areas, most acquisitions have targeted wetlands, particularly those in the prairie-pothole region of the North Central United States. In addition to purchasing land, the program seeks to preserve additional wetlands by acquiring perpetual easements under which landowners exchange their rights to drain, fill, burn, or level **wetlands** for a one-time or annual payment. Although most easement programs have targeted agricultural land, the Migratory Bird Hunting and Conservation Stamp Act authorizes the use of easements more generally. By the end of FY 1989, the program had spent approximately $49 million to obtain easements on 1.2 million acres of wetlands in the prairie-pothole region.

A more recent land-acquisition statute is the North American Wetlands Conservation Act of 1989 (P.L. 101-233), which established a cooperative effort between the United **States,** and Mexico **aimed at conserving or** restoring 6 million acres of wetlands in the prairie-pothole region to help revitalize **waterfowl populations. This act** authorized appropriations of up to $15 million for purchase of, and easements on, wetlands that will accomplish the goal. Although a substantial portion of the money is to be spent on projects in **Canada and Mexico, some 25 to 50 percent of the total may be spent in the** United States. Some funds are to be raised by excise taxes on ammunition, sporting arms, and archery equipment, as well as by fines for violations of the Migratory Bird Hunting and Conservation Stamp Act.

Various other programs support acquisition of wetlands.The Land and Water Conservation Fund Act of 1965 (LAWCON; P.L. 88-578) initiated a fund, bankrolled by fees from offshore drilling, to be used for the purchase of natural areas, including wetlands. Amendments in 1986added explicit authorization for LAWCON funds to be used to purchase wetlands, and further stipulated that States be required to consider wetlands in their **State Comprehensive Outdoor Recreation Plans, which they must complete** to qualify for grants from the LAWCON pool. FWS has used land acquisitions under this program to add to the National Wildlife Refuge System and to acquire crucial habitat areas for protecting endangered species. Critics charge that in recent years, LAWCONfunds have been underutilized and have not **adequately met the** mandate to acquire natural areas.

The Emergency Wetlands Resources Act of 1986 (P.L. 99-845) called for the development of a National Wetlands Priority Conservation Plan to direct the Federal Government's various wetland-protection efforts toward the most valuable areas. The plan was developed by FWS and issued In 1989. The act also authorized funds to acquire wetlands consistent with the plan, and provided various revenue mechanisms to support **wetland-protection and** -acquisition activities.

Several Federal programs support wetland preservation through easements. The Water Bank Act (P.L. 91-559), passed in 1970, established a fund to help preserve, maintain, and restore wetlands. Administered by the U.S. Department of Agriculture’s (USDA’s) Soil Conservation Service (SCS), water-bank funds are used* negotiate easements from farms who agree not to drain, fill, burn, level, or otherwise destroy wetlands or adjacent upland areas. Farmers receive annual payments ranging from $5 to $55 per acreforthe duration of the 10-year agreement (subject to review after the fourth year), after which the contracts maybe renewed. The Water Bank (Program has concentrated on acquiring easements in the prairie-pothoie region, where it had nearly 550,000 acres enrolled as of July 1991, at an annual cost of $8 million. The Conservation Reserve and Wetlands Reserve Programs described in the next section, also negotiate easements for the protection of wetlands.

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[2] To convert acres to hectares, multlply by 0.405

[3] These figures are from reference 95. According to reference 112, the program had spent $102 million to acqulre fee-simple title to 584,000 acres of wetlands in the prairie-pothole region under the Small Wetlands Acquisition Program by the end of FY 1989.

Restoration—Perhaps because more than half of the Nation's wetlands have already been converted to other uses, particularly agricultural, recent policy initiatives have expanded the wetland-protection mandate beyond the early framework of preservation and regulation to include restoration. Several programs attempt restoration of agricultural land. Under the Conservation Reserve Program (CRP), authorized by the Food and Security Act of 1985 (P.L. 99-198), USDA can enter into contracts to pay farmers to remove highly erodible or environmentally valuable lands from production for 10 to 15 years in exchange for annual payments. A provision making farmed wetlands eligible for the conservation reserve was added in 1989. As of July 1991, nearly 34.5 million acres of farmland were enrolled in the CRP. USDA's Soil Conservation Service (SCS) estimates that approximately 410,000 acres were wetlands, for which rental payments were around $20.1 million annually. The wetlands Reserve Program (WRP), established by the Food, Agriculture, Conservation, and Trade Act of 1990 (P.L. 101-824), was established with the goal of restoring up to 1 million acres of wetlands that had been converted to agriculture. USDA's Agricultural Stabilization and Conservation Service (ASCS) makes annual payments for easement under which the farmer agrees to restore the wetlands. In addition, ASCS will provide up to 75 percent of the cost of restoring once-farmed wetlands placed under permanent easement and 50 percent of the cost of restoration for wetlands under 30-year easements.

The mitigation provisions of Section 404 of the Clean Water Act require that applicants for Section 404 permits offset unavoidable wetland impacts through the restoration or creation of wetlands. One party (often a government agency) restores or creates wetlands, t hus establishing marketable credits t hat are held in a bank. The bank can then arrange the sale of credits to Section 404 permit applicants to offset damage to wetlands that may be caused by the permitted activit y, often at a ratio greater than one-to-one. Achieving no net loss of wetlands requires greater than 100 percent replacement to compensate for areas where restoration does not succeed and for the time lag between restoration activities and the return of some measure of function. The permit applicant must purchase enough credit to offset potential wetland losses More t he permitted project begins and wetlands are destroyed. Under current policies, mitigation banking can be used only where loss of wetlands cannot be avoided and where there is no suitable site for restoration on the same property. If key areas for wetland migration are identified through the National Wetlands Priority Plan (described below), a wetland banking program could attempt to target those areas and allow mitigation credits for coastal development.

Other programs that support the restoration of wetlands are the Federal Aid in Wildlife Restoration Act of 1937 (P.L. 99-398), commonly known as the Pittman-Robertson Act and the Federal Aid in Fish Restoration Act of 1950 (P.L. 100-448), the Dingel l-Johnson Act. Through the Pittman-Robertson Act, FWS provides grants to States to cover up to 75 percent of the costs of acquiring, restoring, and maintaining wildlife areas, including wetlands. The act is funded by Federal excise tax on firearm and ammunition sales. The Dingell-Johnson Act uses Federal excise taxes on bait and fishing equipment to fund State projects up to 75 percent for "comprehensive fish and wildlife resource plans," including maintenance and restoration of wetland areas that provide needed habitat.

Coordinated planning and management--Because responsibility y for wetlands is divided among numerous laws, programs, and agencies, several policies have been put in place to coordinate planning and management. Some of these cover wetlands specifically, and others address wetlands within the larger context of natural resources such as water resources, coastal areas, and wildlife and endangered species habitat.

At least four laws and one Executive Order explicitly call for coordination among wetlands-planning and -management agencies. The Emergency Wetlands Resources Act of 1988 (P.L. 99-845) seeks to increase cooperation among the numerous agencies at the Federal, State, local, and private levels that protect, manage, and conserve wetlands. The act calls for FWS to develop a National wetlands Priority Conservation Plan, which would help decision makers at all levels of government identify the most valuable wetlands for protection. The act

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Box 44–The Wetlands Policy Space-(Continued)

also requires that State Comprehensive Outdoor Recreation Plans address wetlands, that FWS complete its wetland inventory mapping by 1988 (24), and t hat FWS conduct a study of how Federal programs affect wetlands. The Water Resources Development Act of 1990 (P.L. 101-640) embodies the call for no net loss of the Nation's remaining wetlands as part of the Army Corps of Engineers water-resources-development program. The act mandated that the Corps develop, in consultation with EPA, FWS, and other interested agencies, an action plan for achieving the no-net-loss goal for wetlands. The Coastal Wetlands Planning, Protection, and Restoration Act (P.L. 101 -646) established a planning process for protecting and restoring Louisiana coastal wetlands, and has been used to support various restoration projects. Executive Order 11990, Protection of Wetlands, was issued in 1977 to direct all Federal agencies to take action in carrying out their individual activities to minimize destruction, loss, and degradation of wetlands and to preserve and enhance wetlands and wetland functions and products.

Other programs that call for coordinated planning and management of wetlands as part of a larger set of natural resource issues include the Coastal Zone Management Act (P.L. 92-583), described in more detail under incentives (below and in vol. 1, ch. 4), the Fish and Wildlife Coordination Act (P.L. 89-72), the Endangered Species Act (P.L. 93-205), the National Environmental Policy Act (P.L. 91-190), and Executive Order 11988 (Flood Plain Management). The Fish and Wildlife Coordination Act requires that wildlife management be considered equal to other purposes in the construction of water-development projects, and authorizes FWS and NMFS to evaluate the potential impacts on fish and wildlife of Federal construction activities and projects being evaluated for Section 404 permits. The National Environmental Policy Act calls for a review of the environmental impacts of all proposed Federal projects, such as road construction and dam building, some of which pose significant threats to wetlands. The Endangered Species Act sets forth a procedure for listing threatened and endangered species and for designating the areas they need as habitat. Federal agencies are prohibited from undertaking or subsidizing any projects that will destroy habitat of the listed species. Because one-third of all listed endangered species depend on wetlands, this prohibition prevents some development in wetlands. Executive Order 11988 requires that all Federal agencies avoid supporting development in floodplain areas, either directly or indirectly; because many wetlands lie in floodplains, this directive could help protect wetlands.

Incentives and disincentives-Approximately 87 percent of the loss of wetlands in the past decade is attributed to agricultural conversions (108). Various Federal programs-including tax incentives, low-interest Farmers Home Administration (FmHA) loans, technical assistance, and commodity and price-support program--during the 1950s through the 1970s either directly or indirectly encouraged conversion of wetlands to agricultural uses. Thus, it is not surprising that many of the incentive and disincentive programs now seeking to protect and restore wetlands target agricultural lands. Furthermore, incentive and disincentive programs are in many cases the Federal Government's only chance to encourage conservation of the 74 percent of the Nation's remaining wetlands that are privately owned. The CRP and t he WRP, described above, offer direct payments to farmers as an incentive to set aside and restore former wetlands.

The Swampbuster program, initiated by the Food Security Act of 1985 (P.L. 99-198) and expanded by the Food, Agriculture, Conservation, and Trade Act of 1990 (P.L. 101-508), hinges on disincentives. As originally written, the Swampbuster program prohibited subsidies only if wetlands were converted (e.g., drained, filled, plowed, and burned)-after December 23, 1986-directly for the purposes of growing commodity crops (crop subsidies are explained in detail in vol. 1, ch. 6). This approach left a large loophole: farmers did not have to cultivate wetlands directly in a subsidized crop in order to boost their commodity acreage; rather, they could plant the wetland in an unsubsidized crop, such as forage, to free up other land to increase acreage for subsidized commodities. The 1990 amendments strengthened the program by calling for denial of crop subsidies if conversions of wetlands were used to boost acreage in commodity crops, even if the wetlands were not directly cultivated (1 12). Farmers caught in violation of Swampbuster regulations lose eligibility for all Federal farm benefits, including commodity programs, crop insurance, and disaster payments, for that year and all subsequent years. As of August 1991, ASCS had withheld approximately $3.7 million in benefits because of Swampbuster violations (112).

Although agriculture has been a major focus of incentive and disincentive programs, legislation has sought to reduce or eliminate incentives for conversion of wetlands in other areas as well. The Coastal Barrier Resources Act (COBRA; P.L. 100-707) prohibits Federal expenditures or financial assistance (in the form of loans, grants, guarantees, insurance, payments, rebates, subsidies, and so on) to be used for development of coastal barrier islands. The act aims to reduce harm to human life, property, and natural resources, and because many coastal barriers are accompanied by wetlands, the withdrawal of Federal incentives to development may result in the protection of coastal wetlands. First established in 1982, the program was considerably expanded by 1990 amendments; the approach it espouses-withholding Federal subsidies-is now widely considered to be a good way to achieve environmental protection at low cost.

The Coastal Zone Management (CZM) Act of 1972 (P.L. 92-583, as amended) was designed to protect, restore, and develop coastal-zone resources and to encourage States to address ecological and aesthetic values, along with economic considerations, in managing their coastal areas. The CZM Act set forth a program in which States develop CZM plans according to certain guidelines imposed by the Federal Government. Because the requirements for CZM plans explicitly mandate the protection of ecological values of coastal resources (which include wetlands), and requirements for the plans already cover issues such as beach protection and shoreline erosion, the CZM program offers an appropriate mechanism through which the Federal Government could encourage the adoption of setbacks, which could allow wetlands room to migrate inland as sea level rises. (For a more detailed discussion, see vol. 1, ch. 4.)

An indirect incentive for wetland conversion that is being reined in is the National Flood Plain Insurance Program (NFIP). Established in 1968 by the National Flood Insurance Act (P.L. 90-448), the intent of the program was to encourage sound development policies in flood-prone areas. The act sought to accomplish this by requiring that communities develop and implement plans to regulate construction in flood plains in exchange for eligibility for Federal disaster-relief funds. Although the intent was to minimize floodplain development (and many wetlands occur in coastal and inland floodplains), the effect was sometimes to encourage development by providing subsidized insurance. The Federal Emergency Management Agency (FEMA), which administers the program, has called for stricter regulations of development in t he most flood-prone areas. (See vol. 1, ch. 4, for more information about flood insurance and other emergency-assistance programs.)

Research, inventory, and monitoring-Research on and monitoring of wetlands is conducted by several different Federal agencies under various programs, as well as by researchers in land-grant and sea-grant institutions, private institutions, and conservation organizations. Over the past two decades, long-term research and monitoring of wetlands has been conducted through programs such as FWS's National Wetlands Inventory and National wetlands Research Center; the National Science Foundation's long-Term Ecological Research (LTER) and Land Margin Ecological Research (LMER) programs; EPA's office of Research and Development and Wetlands Research Program; the National Oceanic and Atmospheric Administration's National Estuarine Research Reserve System, National Estuary Inventory, Estuarine Habitat Program, and sea level monitoring; the Corps' Waterways Experiment Station, Wetlands Research Program, and Dredged Materials Program; USDA's National Resource Inventory (conducted by SCS); various water- and weather-monitoring programs carried out by the U.S. Geological Survey and the National Weather Service; and others. New efforts include FWS's Gap Analysis Project (GAP) and EPA's Environmental Monitoring and Assessment Program (EMAP), which are described in chapter 5.

SOURCES: U.S. Congress, Office of Technology Assessment, *Wetlands: Their Use and Regulation,* OTA-O-206 (Washington, DC: U.S. Government Printing Office, March 1984); D.E. Willard et al., "Wetland Vulnerabilities to Climate Change," contractor paper prepared for the Office of Technology Assessment, August 1992; U.S. General Accounting Office (GAO), *Wetlands Overview:* Federal *and State Policies, Legislation,* and Programs, GAO/RCED-92-79FS (Washington, DC: U.S. GAO, November 1991).

404; many normal, ongoing agriculture and forestry practices are specifically exempted. The program does not cover draining of wetlands unless the activity involves a discharge, nor does it explicitly cover isolated wetlands (i.e., nonnavigable ones) unless there is a connection to interstate commerce (e.g., use by migratory waterfowl). overall, the program protects coastal, and particularly tidal, wetlands relatively well, but the exemptions exclude from coverage activities responsible for approximately 80 percent of the destruction of wetlands (1 12).

Federal acquisition of wetlands deemed particularly valuable for wildlife is done through outright purchase or through the establishment of easements, as authorized by legislation including the Migratory Bird Hunting and Conservation Stamp Act (also referred to as the Duck Stamp Act), the Emergency Wetlands Resources Act of 1986 (P.L. 99-645), and other laws related to the National Wildlife Refuge System. The National Wildlife Refuges now contain some 30 million acres of wetlands. Smaller acquisitions have been made through the National Estuarine Research Reserve System (NERRS), which now holds 425,000 acres of estuarine wetlands and adjacent waters and uplands, and the Marine Sanctuaries Program, which contains some wetlands along with open waters in eight sanctuaries. Additional wetlands have been acquired as part of areas purchased for parks or designated as wild and scenic rivers or wilderness areas (see ch. 5).

Restoration and management of wetlands are carried out through diverse programs. The Coastal Wetlands Planning, Protection, and Restoration Act (P.L. 101-646), passed in 1990, established a restoration cost-sharing program open to coastal States, with a particular--but not exclusive-emphasis on restoring coastal wetlands in Louisiana. NOW'S Damage Assessment and Restoration Program conducts habitat restoration and research in coastal wetlands that have been severely contaminated. The Conservation Reserve and Wetlands Reserve Programs, established by Title XII of the Food Security Act of **1985** (P.L. 99-198) and the Food, Agriculture, Conservation and Trade Act of 1990 (P.L. 101-624) both allow USDA to enter into contracts with farmers to set aside and pay up to 50 to 75 percent of the cost of restoration. Ongoing programs conducted by the Army Corps of Engineers, which is responsible for constructing and maintaining dams, flood-control structures, and navigable rivers and harbors, have given the agency a role in affecting wetlands through engineering techniques such as sedimentation control and use of dredged materials to create or restore wetlands.

Indirect Federal Action

Various incentive programs encourage wetland protection and restoration, and some disincentives have been established to discourage activities that degrade or destroy wetlands. The Water Bank Act (P.L. 91-559) provides payments to farmers as an incentive to refrain from draining wetlands important to migratory waterfowl. The "Swampbuster" provision of the Food Security Act of 1985 withdraws Federal benefits (i.e., crop subsidies and disaster insurance) from farmers who drain wetlands. The Coastal Barrier Resources Act (COBRA; P.L. 100-707) denies such benefits as flood insurance and infrastructure support to development projects that would alter coastal barrier islands to the point where they would be unable to provide certain fictions, such as erosion control. The Tax Reform Act of 1986 (P.L. 99-514) disallowed deductions for farm expenses incurred in draining wetlands (e.g., by constructing drainage ditches).

Coordination and *Research*

At least four laws and one Executive Order explicitly call for coordination among agencies responsible for wetland planning and management, and at least seven agencies plus numerous private and conservation organizations conduct research on and limited surveys of wetlands. The "Coordinated Planning and Management" and "Research, Inventory, and Monitoring" sections in box 4-I describe these programs. Despite these and other programs, however, no coordinated long-term Federal effort tracks the overall quality of wetlands nationwide.

State, Local, *and Private Programs*

In addition to the many Federal programs, States, municipalities, and private conservation organizations also share responsibilities for protecting wetlands. States and municipalities play a major role in regulation through their implementation of land-use controls and planning. Loca1 land-use efforts, such as storm-water management and setbacks (see vol. 1, ch. 4) from wetlands and adjacent areas, can be effective in maintaining wetlands and their functions. Many States have also adopted various measures that address coastal, inland, or all wetlands within their boundaries, either specifically or in the context of water-quality control and broader mandates to protect natural areas (see table 4-2).

State and local parks and refuges are key to preserving the natural values of wetlands (see ch. 5). Private conservation groups such as The Nature Conservancy, the Audubon Society, and Ducks Unlimited, in addition to numerous regional and local land trusts, join the effort to protect and maintain wetlands.

Because many different organizations at all levels of government, along with private agencies, conduct programs that affect wetlands, any Federal efforts to respond to the impacts of climate change on wetlands must recognize and interact with the full range of programs. In many cases, State and local agencies have the ability to form partnerships with Federal agencies to accomplish things that Federal agencies by themselves cannot.

POLICY OPTIONS

OTA has identified many actions that the Federal Government could take to help protect existing wetlands, restore degraded areas, facilitate migration, and promote coordinated management and monitoring. These actions, summarized in table 4-3, run the gamut from incremental changes in existing programs to major policy revisions or additions. Many of the strategies are interconnected, comprising different approaches for accomplishing the same goal. To cope most effectively with the potential impacts of climate change on wetlands, the best approach would be to undertake the strategies together. A specific set of options, based on measures that are particularly feasible or urgent and on opportunities that may arise in upcoming legislative reauthorizations, should be pursued. Those options are suggested in the final section of this chapter, "First Steps."

■ Protect Existing Wetlands

Minimizing the current rate of loss should be the first priority of any comprehensive plan to help wetlands adapt to climate change. As noted above, the Nation has already lost more than half its wetlands. Maintaining what is left is a necessary first step to ensure that some wetlands will persist regardless of the rate and severity of climate change. An active protection strategy will yield benefits even if climate change proceeds more slowly or less severely than predicted. The goal of protecting existing wetlands has received widespread and bipartisan support and, despite the difficulties in achieving it thus far, that goal should remain. Climate change only makes protection efforts more urgent.

Direct Federal Action

Option 4-1: *Implement and oversee the no-net-1oss policy. The* no-net-loss policy has not yet been incorporated into the legal and regulatory framework in inexplicit and accountable way. In 1991, the Administration issued a plan for protecting wetlands that would include strengthening acquisition programs, revising the wetland-delineation manual, and improving regulation of wetlands under Section 404 of the Clean Water Act (25, 112). Although a few of the specific provisions of the plan were implemented, many of the more significant changes were not, due in

Table 4-2—Responding to Climate Change Impacts on Wetlands: Summary of Reported State Wetland Protection Programs[a]

State	Coastal permit program	Freshwater nontidal program	Comprehensive coastal and inland program	Formal policy, regulation, or guidelines for issuing Section 401 certification for wetlands
Alabama	●	—		●
Alaska	—	—		●
Arizona	NA	—		●
Arkansas	NA	—	—	—
Connecticut	NA	—	●	●
Delaware	●		—	—
Florida	●	■	●	●
Georgia	●	—	—	—
Hawaii	—	—	—	●
Illinois	—	—	◆	—
Indiana		—	—	●
Iowa	NA	—	—	●
Kansas	NA	—	—	●
Kentucky	NA	—		●
Louisiana	●		—	●
Maine	●	■	●	—
Maryland	●	◆	—	●
Massachusetts	●	■	●	●
Michigan	●	●	●	●
Minnesota	—	—	—	●
Mississippi	●	—	—	●
Missouri	NA	—		●
Nebraska	NA	—		●
Nevada	NA	—	—	●
New York	●	●	●	●
North Carolina	●		—	●
North Dakota	NA	—		—
Ohio	—	—		●
Oklahoma	NA	—	—	●
Oregon	●	●	●	●
Pennsylvania	●	■	●	●
Puerto Rico	—	—		●
Rhode Island	●	●		●
South Carolina	●			●
South Dakota	NA	■	—	—
Tennessee	NA	●	—	●
Texas	—	—	—	●
Vermont	NA	●	●	●
Virginia	●	—		●
Washington	—	—		●
West Virginia	NA	—	—	●
Wisconsin	●	■	●	

[a] ●=Program in place; +=program in place, legislation enacted but not yet implemented, regulations to be developed; D=program in place, can be delegated to local or regional authorities; —=no data; NA=not applicable.

SOURCE: U.S. Environmental Protection Agency (EPA), National Water Quality *Inventory* 1990 Report to Congress (Washington, DC: U.S. EPA, 1992).

Table 4-3--Examples of Laws and Agencies That May Be Affected by Various Policy Options[a]

Option	Affected laws and/or agencies
Protect existing wetlands	
Implement and oversee the no-net-loss policy,	CWA-reconstituted WRC
Expand coverage and strengthen enforcement of CWA Section 404.	COE, EPA, FWS, NMFS
Acquire key wetlands that may be lost soon	FWS, NPS, NOAA
Design Federal projects to incorporate climate change predictions and safeguard water and sediment flow to wetlands	NEPA, COE, BOR
Augment and coordinate monitoring of wetlands	All agencies coordinated under interagency task forces; FWS, EPA, USGS, NMFS
Require direct payments	WRP, Water Bank Act
Require traded obligations	U.S. Tax code, CWA, Swampbuster
Eliminate Federal incentives for wetland destruction.	ASCS and SCS cost-sharing; COBRA
Restore degraded or converted wetlands	
Fully fund existing restoration programs.	WRP
Require that restoration projects set goals and monitor and evaluate success.	CWA
Use opportunities to restore and preserve reclaimed wetlands,	FmHA CEP; DOD base closures
Remove hard engineering structures that degrade wetlands; restore normal water and sediment flow,	COE, BOR, FERC review
Utilize dredged-materials program to facilitate wetland restoration,	COE
Target key areas for wetland restoration programs.	CWA, COE, EPA, FWS, NMFS
Improve coordinated management and monitoring	
Identify, assign priorities to wetlands important now, under climate change,	LAPS, GAP, C-CAP, NWPCP, NAWMP, EMAP
Clarify national goals for wetland protection,	CWA; EO 11990
Ensure that Federal policies do not inadvertently lead to loss of wetlands.	CWA, CZMA, COE, ASCS, SCS, OEP, Swampbuster
Promote integrated resource management at the watershed level by offering financial and other incentives.	NFIP, CZMA
Use legislative reauthorizations to explore new ways to protect biodiversity and ecosystems and to integrate preservation and restoration.	CWA, ESA, DOI, NPS, NBS
Support research on the impacts of climate change on wetlands	EPA, NOAA, FWA, NMFS
Facilitate migration	
Require building setbacks from coastal and riparian wetlands	CZMA, NFIP
Identify wetlands most able to migrate and sites to which they could migrate.	LAPS, GAP, C-CAP, NWPCP, NAWMP, EMAP
Acquire lands important for migration (including buffer zones).	Duck Stamp Act, LWCF, WRA, WRP and CRP
Reduce Federal subsidies such as CZMA funds and flood insurance in areas that have not established setback or "planned-retreat" policies.	CZMA, NFIP

a ASCS=Agricultural Stabilization and Conservation Service; BOR=Bureau of Reclamation; C-CAP= Coastwatch-Change Analysis program; CEP=Conservation Easement Program; CoBRA=Coastal Barrier Resources Act; COE=U.S. Army Corps of Engineers; CRP=Conservation Reserve Program; CWA=Clean Water Act; CZMA=Coastal Zone Management Act; DOD=U.S. Department of Defense; FWS=U.S. Fish and Wildlife Service; EMAP=Environmental Monitoring and Assessment Program; EPA= Environmental Protection Agency; ESA=Endangered Species Act; EO=Executive Order; FERC=Federal Energy Regulatory Commission; FmHA=Farmers Home Administration; GAP=Gap Analysis Program; LAPS=Land Acquisition Priority System; LWCF=Land and Water Conservation Fund; NAWMP=Norfh American Waterfowl Management Plan; NFIP=National Flood Insurance Program; NEPA=National Environmental Policy Act; NOM= National Oceanic and Atmospheric Administration; NMFS=National Marine Fisheries Service; NPS=National Park Service; NWPCP=National Wetlands Priority Conservation Plan; OEP=Office of Environmental Policy; SCS=Soil Conservation Service; USGS=U.S. Geological Survey; WRA=Emergency Wetlands Resources Act; WRC=Water Resources Council; WRP=Wetlands Reserve Program,

SOURCE: Office of Technology Assessment, 1993.

large part to the controversy that surrounded the proposals. Two previous Executive Orders addressing activities that could destroy wetlands are also still in effect (No. 11990, Protection of Wetlands, and No. 11988, Floodplain Management); although many agencies have promulgated rules and regulations in accordance with these directives, no oversight mechanism exists.

Implementation and oversight of the no-net-loss policy could be achieved in several ways. The Water Resources Council (WRC), which operated from 1967 until 1982 to recommend coordinated water policies and oversee the integrated plarnning efforts of river basin commissions, could be funded again with oversight of wetlands as a key function.[17] (See vol. 1, ch. 5, for more discussion of the WRC.)

Alternatively, an interagency committee or task force, composed of representatives from each agency whose activities affect wetlands, could be appointed and directed to) oversee wetland policy and to maintain an inventory of the quantity and quality of wetlands. The leadership of the task force could rotate among the members, or the task force could be placed under the coordination and oversight of the new White House Office of Environmental Policy (OEP), which could play a role similar to that of the Council on Environmental Quality in the past. Both types of bodies would be primarily advisory. A third alternative would be to appoint a single lead agency to oversee the implementation, but such a designation may cause contention among the several agencies that could legitimately claim a leading role. This coordinated effort could oversee wetland research and data gathering as well.

No matter which institution is selected to implement and oversee the no-net-loss policy, no single regulatory program can by itself accomplish the goal. That will require coordinated effort by many agencies under many programs, including programs that affect wetlands only indirectly. Furthermore, active Federal oversight of the no-net-loss policy will not eliminate problems that stem from unclear goals for wetland protection (discussed in more detail below), but it could help to minimize them.

Option 4-2: *Expand coverage and strengthen enforcement of CWA Section 404. The* no-net-loss policy is also constrained by the fact that the Clean Water Act Section 404 permitting program (described in box 4-I and ch. 5) covers activities responsible for approximately 20 percent of the destruction of wetlands (112). Permits cover only activities that involve discharges of dredged or fill material, but not activities such as water diversions, draining, channeling, and clearing that may also destroy wetlands but that do not involve a discharge. These constraints allow for incremental losses that appear small, but have a large cumulative effect (1 15). Even where permits do offer the Federal Government a powerful lever with which to control impacts on wetlands, goals for protecting wetlands are not clearly stated in Section 404. Thus, expanding the coverage of Section 404 to include more activities and small wetlands could greatly increase protection of existing wetlands (88).

Even where Section 404 could cover a given area and activity, program implementation is decentralized and has not been uniform across regions. Other limitations are the large number of permit applications that must be reviewed each year (approximately 15,000 individual permits) and the limited resources with which to conduct the review and to monitor compliance. The Section 404 permit program could be enhanced by increasing finding and by requiring that individual permit decisions be selectively reviewed by an oversight body, as recommended above, for consistency and adherence to the goals of wetland protection,

Option 4-3: *Target acquisition programs to wetland types that may be lost soon. Several*

[17] The Council, authorized by the Water Resources Planning Act of 1965 (PL. 89-80), was never officially d ismantled, but the funding was discontinued. Reconstituting the Council would require appropriations rather than new legislation.

programs seek to preserve wetlands by either acquiring the land outright or acquiring perpetual easements under which landowners exchange their rights to drain, fill, bum, or level wetlands for a one-time or annual payment (see box 4-I). These acquisition programs are, however, constrained by limited funds. For example, FWS has about $150 million per year to spend on all acquisitions (not just on wetlands), and funds are limited in other programs as well.

Federal acquisition programs are not likely to be expanded given the currently tight restrictions on all new Federal expenditures. Thus, it is essential that ongoing acquisitions made with existing funds focus on important areas currently in danger of being lost. Developing a list of high-priority wetlands within an integrated-resource-management framework (described below) will help direct funds to areas and wetland types that are either insufficiently protected now or that could be especially vulnerable to climate change.

Option 4-4: *Design Federal projects to incorporate climate change predictions and to safeguard water and sediment flow to wetlands. The* environmental impact statements (EISS) required under the National Environmental Policy Act (NEPA; P.L. 91-190) are intended to ensure that the potential environmental impacts of projects that the Federal Government oversees are carefully considered and disclosed to the public. However, wetlands have continued to be degraded in many areas despite the EIS process, in part because wetlands are easily affected by alterations in water and sediment flow in adjacent areas-even if the wetland itself is not dredged or filled. Since 1989, the Army Corps of Engineers has had a policy of evaluating current and potentially accelerated rates of sea level rise as part of its planning process (94). NEPA, or its implementing regulations, could be amended to require that all future Federal projects consider the effects of the proposed action on the water and sedimentation regimes that supply wetlands, both now and under climate change.

Option 4-5: *Augment and coordinate monitoring of wetlands.* Although numerous research and monitoring programs cover some aspect of wetlands, no single program comprehensively addresses the quantity and quality of wetlands today. The National Wetlands Inventory (NWI) conducted by FWS has been invaluable in recent efforts to understand patterns of wetland loss. However, its statistical sampling methods can only reveal gross changes in the amount of wetlands. NWI cannot supply information on the status or quality of the wetlands not sampled. The ongoing National Water Quality Assessment conducted by the U.S. Geological Survey (USGS) measures water-quality patterns nationwide but does not relate water quality to loss or degradation of wetlands. EPA's Environmental Monitoring and Assessment Program (EMAP) was initiated in 1987 to assess and report on the status and trends of ecological conditions in U.S. natural resource systems. EMAP includes a wetland program that aims to evaluate and monitor the quantity and quality of wetlands on a regional scale. The program is still in the pilot stage, but it could provide a sound basis for coordination if a consensus can be reached on data-collection protocols and dissemination. The Department of the Interior's (DOI'S) Gap-Analysis Program (GAP), described in a later section, also offers potential for coordinated monitoring. Finally, the National Biological Survey (NBS), a program recently initiated by DOI, may prove invaluable to coordinated monitoring and management among agencies (see ch. 5). The goals of NBS are to combine biological research activities within DOI into an independent, non-advocacy biological science arm.[18]

The Federal Government could strengthen the protection of wetlands by reducing the overlap of these and other existing research and monitoring efforts. Coordinated monitoring could help iden-

IS E. T. LaRoe, Director, Cooperative Research Unit Center, U.S. Fish and Wildlife Service, personal communication, March 1993.

tify **areas** that should be protected now, and could provide a baseline against which to gauge the future impacts of climate change. Increased funding for programs such as EMAP, GAP, and NBS, along with other monitoring and inventory efforts, would aid in coordinating these efforts among the agencies (see ch. 5).

Indirect Federal Action

The Federal Government could attempt to make it difficult to destroy wetlands and profitable to preserve them. Numerous programs over the years have offered direct or indirect subsidies or incentives to private landowners for construction in wetlands and flooddplains. Among these are the U.S. Tax Code, which for decades allowed tax write-offs for the construction of drainage and irrigation systems (often resulting in the conversion of wetlands to agricultural uses); various crop-support and commodity programs (see vol. 1, ch. 6); and federally supported disaster and flood insurance, which may have the unintended effect of promoting development in flood-prone areas. (Disaster and flood insurance are discussed in more detail in vol. 1, chs. 4 and 5.) To minimize the loss of wetlands, subsidies and tax incentives for protecting wetlands should be created or expanded while subsidies and incentives for converting wetlands should be reduced or eliminated.

Option 4-6: *Pay to protect wetlands on private property. This* kind of program pays landowners to refrain from destroying wetlands. Under programs such as the Water Bank Act and the Duck Stamp Program (under the Migratory Bird and Conservation Stamp Act), Congress has given agencies authority to pay farmers who agree not to drain, plow, burn, or otherwise harm wetlands on their property. Funding for such programs could be increased or at least maintained at the authorized levels.

Option 4-7: *Allow trading of regulatory or tax obligations for wetland protection.* A reduction in existing regulatory or tax obligations can be traded for wetland protection. For example, the Federal Government could create tax incentives for granting conservation easements on wetlands, or for outright donations of wetlands to conservation agencies. The Tax Reform Act of 1986 decreased the deductions possible for charitable giving, which includes the granting of conservation easements to Federal or State agencies. Introducing the tax incentives for wetland preservation could assist protection efforts. The Open Space Preservation Act of 1991 (H.R. 2149), introduced during the 102d Congress, sought to accomplish this goal.[19]

Some form of traded obligations might also be used as part of watershed-based efforts to achieve pollution control. The acquisition and restoration of wetlands near water bodies could be used as one element in a comprehensive water-quality program. Such wetlands could serve as water-filtering buffers to help control non-point-source pollution from agricultural lands and urban areas. Many communities have had to support expensive tertiary treatment processes at their sewage treatment plants in order to meet the stricter water-quality standards under the Clean Water Act, even though non-point-source pollution constitutes a significant part of the problem. Despite investments of $260 billion (1990 dollars) in the construction of sewage treatment plants during the 1970s and early 1980s, the non-point-source-pollution problems in many water bodies, such as the Chesapeake Bay, have still not been resolved (68).

Municipalities and States that are able to acquire, restore, and maintain sufficient amounts of wetlands to attain measurable improvements in water quality might be permitted to delay or scale down installation of additional sewage-treatment capabilities within the same watershed. Effluent

[19] H. R. 2149 proposed to 'exclude from the gross estate the value of land subject to a qualified Conservation easement if certain conditions are satisfied and to defer some of the scheduled reduction in estate tax rates. '

from sewage treatment plants or storm-water drainage should not be discharged directly into existing wetlands, although some municipalities have constructed wetlands specifically for that purpose. Alternatively, some portion of the Federal grants to States for constructing treatment plants could be used for purchasing wetlands located in areas within the watershed (see vol. 1, ch. 5, options 5.1 and 5.2). Any program designed to use wetlands to help control non-point-source pollution would have to carefully avoid degrading existing wetlands.

Option 4-8: *Eliminate incentives to destroy wetlands. The* Swampbuster program (see box 4-I) is a prime example of reducing Federal benefits-in this case, crop subsidies and disaster payments— in order to protect wetlands. Swampbuster could be expanded to cover any activities adjacent to wetlands, such as ditching and diverting water for irrigation purposes, that result in destruction of wetlands.

For wetlands on federally owned land, including a significant share of the riparian wetlands in the West, the Federal Government could use fees charged for grazing permits to create an incentive for lessees to protect riparian areas from overuse by cattle. Offering a fee reduction or rebate to lessees who implement certain measures for restoring riparian wetlands might be an alternative way to protect wetlands on Federal land.

A far-reaching proposal that has received considerable attention since it was proposed by DOI in 1983 is to “CoBRAcize wetlands,” that is, to adopt an approach for all wetlands similar to that used in the Coastal Barrier Resources Act, which eliminates Federal subsidies that indirectly support destruction of coastal barrier islands (see box 4-I and vol. 1, ch. 4). COBRA denies flood insurance, new Department of Veterans Affairs and Farmers Home Administration (FmHA) loans, Urban Development Action Grants, Community Development Block Grants, road-building monies, and other Federal support to development projects that would alter the natural functions of coastal barrier islands. The program increases environmental protection while saving the Government money, provides an alternative to land acquisition as a means of protection, does not interfere with any State or local programs, and avoids the issue of property takings (50).

Restore Degraded or Converted Wetlands

Recent reports documenting the extent to which wetlands have been destroyed over the past two centuries have stimulated the development and use of methods to restore them (see box 4-A). Restoration of wetlands has already been done with varying degrees of success, and the goal of restoring them to compensate for historic losses has been promoted by both the National Wetlands Policy Forum (NWPF) and the National Research Council (NRC). NRC recommended that the Nation undertake a program to restore 10 million acres of degraded wetlands by the year 2010 (68).

Within the Federal Government, restoration is practiced in two distinct contexts. On public lands, wetlands may be restored, created, or enhanced as part of the overall management strategy of wildlife refuges and other natural areas, or as a way to aid in flood control and maintenance of water quality.[20] In the regulatory setting, restoration may be performed for the purpose of mitigation-that is, the Government may require developers to restore or create wetlands in exchange for receiving a CWA Section 404 permit if damage to wetlands cannot be avoided. There are still many questions concerning the success rates of these practices.

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[20] As currently used by wetland scientists, *restoration* means “returned from a disturbed or totally altered condition a previously existing natural or altered condition by some action of man,” whereas *enhancement means ‘‘the increase in* one or more values of all or a portion of an existing wetland by man’s activities, often with the accompanying decline in other wetland values. ’ For example, efforts to enhance the value of a wetland as habitat for migratory waterfowl may include pumping water into the wetlands or controlling water levels; although this may make the area more attractive for ducks, it may affect other functions such as flood control *or* biodiversity. Creation is ‘‘the conversion of a persistent non-wetland area into a wetland through some activity of man” (R.R. Lewis, in ref. 59).

Little comprehensive monitoring has been performed to document the success of restoration efforts in either context (37, 59). The evaluations that have been done suggest that restoration has been most successful in coastal and estuarine wetlands. It has been somewhat less so in riparian areas, forested or shrub-dominated freshwater wetlands, and other areas where the hydrology is not well-understood. Restoration is problematic for isolated prairie potholes, which are typically fed by groundwater. Flood-control and waterfowl-production functions are the most readily restored; rejuvenating fisheries and other biological functions, as well as pollution filtering and aesthetics, is typically more difficult (59). Restoration projects may fail because people do not understand well enough how these systems work, the construction supervision is improper, the location of the project is innapropriate, or management plans for the area once it has been restored are lacking.

It is probably impossible to fully recreate or restore a wetland, or any other natural system. Any attempts at restoration in exchange for unavoidable alterations to wetlands must ensure that the uncertainty about the success of the project is taken into consideration. Nonetheless, within the broader context of managing and conserving wetlands under changing climate conditions, restoration is likely to become an increasingly important part of the effort.[21] A coordinated management policy would seek to preserve and restore a range of wetlands from coastal to inland areas within a watershed.

Various programs enacted over the past decade have sought to restore wetlands to make up for past degradation and 1oss.[22] The Wetlands Reserve Program (WRP), established in 1990, aims to set aside and restore up to 1 million acres of wetlands that had been converted to agriculture (see box 4-I). The Coastal Wetlands P1anning, Protection, and Restoration Act set forth a program and authorized funds for protecting and restoring coastal wetlands, particularly in Louisiana. The act also provided funds for restoration projects on approximately 6 million acres of wetlands important for migratory waterfowl—with an emphasis on the prairie-pothole region-as called for in the Fish and Wildlife Service's North American Waterfowl Management Plan. Mitigation-banking efforts under Section 404 can incorporate restoration of wetlands, referred to here as *wetland banking. This ap*proach to wetland conservation allows wetlands to be destroyed-when destruction is unavoidable-in exchange for restoring comparable wetlands elsewhere. Federal funds slated for improving grazing lands or other resources could be targeted for wetland restoration and enhancement.[23] Alternatively, because receipts from grazing fees are dwarfed by revenues from timber and recreation on Federal land, perhaps more of these monies could be channeled to protection and enhancement of the riparian wetlands in arid regions.

Option 4-9: *Fully fund existing restoration programs.* Farmers selected to participate in the WRP must develop restoration plans for lands to be set aside as part of the wetland reserve. The Federal Government pays up to $50,000 per year to landowners for property easements and shares 50 percent of the restoration costs on lands covered by 30-year easements. For lands under permanent easement, the Federal Government

21 Efforts to create wetlands may also be necessary, although generally restoration is preferable because it is more successful and less costly (37, 59).

22 No@ however, that restoration goals may vary within and among regions. For example, in urban areas, flood control and water filtering are highly valued functions of wetlands. Restoration of these functions does not require a fully vegetated wetland that supports fish and wildlife; the most important part of restoring these functions maybe simply to clear obstacles from the site and plant enough vegetation to anchor the soil. In other sites, including those in areas important for wildlife but in which considerable habitat has been destroyed, a more complete restoration project to rehabilitate a broader range of functions, including wildlife habitat, may be preferred.

23 Currently, 5(.) percent of Bureau of Land Management and Forest Service grazing- fee receipts are targeted for improving rangelands under the Federal Land Policy and Management Act of 1976 (P.L. 94-579).

reimburses 75 percent of the costs. The WRP goal to set aside and restore up to 1 million acres of wetlands over a period of 5 years has been hampered by funding cutbacks. The WRP program received $46 million in funding during its fist year (1991), but in 1992, Congress eliminated all funding for the WRP for FY 1993 (55). In the 1995 Federal budget, funding has been restored to $65 million, with a goal of enrolling some 75,000 acres in the program during the year. Additional wetland-reserve easements may be purchased with emergency funds authorized for Mississippi flood relief.

Other restoration efforts include the Army Corps of Engineers' Wetlands Research and Dredged Materials Programs, which use dredged material for wetland-restoration projects; NOAA's Habitat Restoration Program, a program directed specifically at coastal wetlands; and the interagency Coastal America program based in Washington, DC, which operates at the national, regional, and local levels to coordinate restoration and mitigation projects. If these programs were to address wetlands that lie somewhat above the present sea level, they might be able to provide a buffer against the loss of coastal wetlands to accelerated sea level rise.

Option 4-10: *Increase Government oversight of restoration and mitigation; require that projects set goals to monitor and evaluate success. Typical goals in* restoring wetlands include the maintenance of enough vegetation to aid flood control or water retention and the restoration of some habitat for fish and wildlife. Fully restoring all natural functions of a wetland has proved very difficult to do, and each case presents different challenges. However, among the goals that can reasonably be expected for all projects are sustainability and adaptability: the restored wetland should be able to survive the range of current conditions and adapt to at least small changes in climate. Clear goals and a comprehensive understanding of wetland processes will increase the probability of the success of restoration efforts.

The Federal Government could enhance restoration efforts by increasing oversight of and guidance to the States and local agencies that ultimately manage the process. Different strategies are needed for efforts on public land (restoration) and private land (mitigation). For restoration projects on public land, an interagency committee could be convened to administer the program. For mitigation projects on private lands, CWA regulations could include explicit directions calling for goals to be clearly identified at the outset of any project, as well as for long-term monitoring to be conducted to ensure that the goals are achieved. In addition, there would have to be mechanisms for collecting, storing, and analyzing data and for evaluating the success of the project over time.

The Federal Government can also set standards for contractors who perform restoration and can train the regulators who oversee the projects. One approach for managing the restoration of wetlands under Section 404 mitigation requirements is to have private parties pay into a restoration fund and let the Government contract out the work to approved technicians. The private parties benefit because they have an interest in the project's success, and the approach would also facilitate Government oversight because contractors who did not perform to standards could be barred from participating in future projects.[24]

Option 4-11: *Use opportunities to restore and preserve reclaimed wetlands. The 1987* Agricultural Credit Act (P.L. 100-233) established the Farmers Home Administration Conservation Easement Program (FmHACEP), which authorizes USDA to grant or transfer easements for the preservation of lands that have reverted to the FmHA through farm foreclosures or voluntary conveyance. The program is not aimed at wetlands, but it could be used to assist restoration of wetlands that have been converted to agriculture. Not all repossessed lands merit easements because agricultural use often transforms wetlands past the point of return by draining, channeling,

24 K. L. Erwin, Consulting Ecologist, Inc., personal communication November 1992.

and filling, but full use of the program could bolster restoration efforts.

Another potential opportunity for reclaiming and restoring wetlands is provided by military-base closures. Decisions on the disposition of land in closed military installations could include consideration of whether wetlands exist or could be restored, particularly in sites containing functions, species, or habitat that are not well-represented in existing preserves, or in areas where the flood- and erosion-control functions would be highly valued.

Option 4-12: *Remove hard engineering structures that degrade wetlands, where feasible, and attempt to restore normal water and sediment flow.* A vital first step in restoring many degraded wetlands is to restore normal water and sediment flows in river and hydrological systems that have been altered. Construction of water-supply and -control structures has in the past often led to unforeseen damage to wetlands both upstream and downstream. This became vividly apparent with the Mississippi River flooding in the summer of 1993. The system of levees along the banks of the Mississippi has isolated it from the wetlands that once absorbed and slowed food waters. The levees have made the river deeper and swifter, with the consequence that when a breach occurs-as happened repeatedly during the recent flooding-the resulting flood is much more destructive than it would otherwise have been.

In some areas, there may be opportunities to remove structures not vital to the protection of developed areas. Both the Corps and the Bureau of Reclamation could review whether existing structures associated with the degradation of wetlands are still necessary and appropriate. Given the extensive damage due to the flooding of the Mississippi, Congress might consider removing some of the levees, allowing certain undeveloped areas to seine as floodwater-detention areas, and restoring wetlands within these areas. These flood-detention areas might also be targeted for conservation-reserve and wetland-reserve expenditures (see option 4-13 and the "first steps" at the end of the chapter).

The Corps, for example, has already begun to modify the structures that forced Florida's meandering Kissimmee River into a straight channel, which led to destruction of wetlands and wildlife habitat. Alleviation of impacts from water-diversion projects should receive high priority because restoring natural water regimes in a wetland plays an essential role in restoring the functions. Efforts to conserve the coastal wetlands of Louisiana, described in box 4-F, illustrate some approaches to restoring water and sediment flow. For example, the Mississippi River Gulf Outlet is a navigation channel that could be considered for modification because it is no longer used, but its presence allows salt water to flow into and harm freshwater wetlands (1 13).

Option 4-13: *Use the Dredged Materials Program to facilitate wetland restoration.* During the past decade, the by Corps of Engineers has dredged an average of 334 million cubic yards (255 million cubic meters)[25] of material annually, from rivers, harbors, and estuaries, to maintain navigable waterways and for other purposes. Some of this material could be used to replace sediments in subsiding coastal wetland areas or in areas that may be inundated if sea level rises. One estimate suggests that 103 square miles (270 square kilometers)[26] could be covered to a thickness of 3 feet each year with uncontaminated dredged material.[27] However, the use of dredged material to restore wetlands is controversial because some of this materialism contaminated and could be harmful to wetland vegetation and wildlife. The Corps has been directed to dispose of dredged material in the least costly manner, which is usually at sea. However, if the States

[25] To convert cubic yards to cubic meters, multiply by 0.765.

[26] To convert square miles to square kilometers, multiply by 2.590.

[27] L. Vallianos, Policy and Special Studies Division, Institute for Water Resources, U.S. Army Corps of Engineers, personal Communication July 19, 1993.

wish to put the dredged material to some use, the Federal Government will contribute half of the increased costs of disposal if States pay the other half. If the Federal Government wishes to promote the use of uncontaminated dredged material for wetland restoration and enhancement, it may want to increase the subsidy it currently gives to the States.

Indirect Federal Action

Option 4-14: *Target key sites for a wetland-restoration program.* Wetland restoration has been attempted inside and outside the regulatory process. More of an effort must be made in the preliminary stages of projects to develop sound construction and implementation plans. Equally important are the development and application of monitoring and evaluation plans.

Small-scale successes in restoration projects could be used as models for larger-scale efforts, and an expanded regional restoration program could be created to target high-priority areas within watersheds for restoration. It could incorporate planning and management for restoration on public lands, as well as restoration for Section 404 permits. This way, a full array of wetlands could be maintained and restored, which would offer the broadest range of adaptive possibilities. A broader strategy for restoring wetlands, termed *wetland banking*, could be keyed to the watershed level to create a market for wetland restoration in cases where destruction of wetlands cannot be avoided. Wetland banks allow for the marketing of credits for wetland restoration and creation as part of the CWA Section 404 program (see box 4-A). A watershed-level wetland bank may be better able to protect functions and products of wetlands than could numerous individual on-site mitigation efforts.

So far, wetland banks, have been used very little, and most of them have been setup by State transportation departments rather than by private industry.[28] Still, they offer greater potential for Federal or regional government oversight than do site-by-site mitigation efforts. As noted earlier, individual mitigation projects are difficult to enforce effectively, and the goals of mitigation projects have often not been stated clearly enough to determine whether the project succeeded (31).

Current Section 404 practice requires that a wetland be restored to the extent practicable, as determined by the Army Corps of Engineers and EPA. However, specific criteria that can be used to measure the success of a project designed to restore wetland functions is often lacking. Furthermore, under standard permit requirements, individual mitigation efforts are to be undertaken ‘‘on site’ and ‘in kind’ wherever possible--that is, wetlands are to be restored on or near the original site, with the attempt to duplicate the characteristics of the original wetland. However, if these objectives are not applied carefully within the context of the overall watershed, they can inadvertently lead to the development of numerous small, isolated, and fragmented restoration projects (such as a pond surrounded by shopping-mall parking lots or tucked between the buildings of an office complex). Larger, better-connected projects are preferable and more likely to succeed. Regional wetland-restoration projects might best preserve habitat values. Some resource managers have suggested, for example, that restoring wetlands adjacent to the Everglades would be a better strategy than on-site mitigation for wetland losses in the urban corridor of coastal South Florida because it would reestablish historic water flows and effectively recreate a larger, contiguous wetland.

Failure to recognize that various wetlands and their functions are not interchangeable has led to the downfall of some mitigation projects. A regional wetland-restoration strategy could avoid some of the problems of case-by-case mitigation by encouraging mitigation projects on the watershed level-on the basis of an evaluation of the overall distribution and functions of wetlands

[28] M. J. Bean, Senior Attorney, Environmental Defense Fund, personal communication, Oct. 16, 1992.

within the watershed-and by targeting mitigation to areas that need it the most. By allowing developers to pay into a bank, rather than contracting mitigation projects individually, a wetland-banking system could allow greater Government oversight and more rigorous standards for restoration. Finally, by combining the planning and management of Section 404 mitigation with the restoration projects that take place on Federal lands, the Government could achieve greater integration of its wetland-protection and -restoration goals.

Standards for mitigation banking have been proposed as guidelines in some regions by the Corps and EPA but have not been uniformly imposed.[29] Additional Federal guidance could link mitigation to a watershed-based priority plan that seeks to maintain an array of wetlands. Participation in regional wetland-restoration schemes should not take the place of avoiding impacts to wetlands. Where destruction of a particular wetland cannot be avoided, however, regional restoration projects could offer additional leverage for implementing wetland-restoration goals on a watershed basis. The regional restoration schemes could require that more wetland areas be restored or created than destroyed.

■ Facilitate Migration

The biggest issue facing coastal wetlands is whether they will have room to migrate as the sea level rises.[30] Because so many coastal wetland areas already have a limited potential to grow, the remaining areas for coastal wetland migration could be identified and protected, either through direct acquisition or through a program of easements. Vegetation in riparian wetlands may also need to migrate toward new sites along rivers and streams. Regional predictions of climate change effects will probably not be available for a decade or so, which will make identification of lands needed for wetland migration difficult. However, if planners and managers do not initiate efforts now to identify where wetlands will be lost first and where wetlands might be able to relocate, the Nation may be ill-prepared to take advantage of the advances in global climate modeling to protect its natural resources. (See ch. 2 for a discussion of climate models.) While this information is being developed, sensible land-use policies-particularly in coastal areas--can be implemented to allow wetlands to persist as well as to reduce property loss and Federal payments such as disaster relief and subsidized flood insurance (see also vol. 1, ch. 4).

Many measures that could assist migration of wetlands will involve State and municipal land-use laws and plarnning efforts. Although the participation of States and municipalities is vital, the following sections focus on Federal actions, including those that might provide incentives for appropriate programs at the State and local levels.

Direct Federal Action

Option 4-15: *Require building setbacks from coastal and riparian wetlands.* A national policy requiring buildings to be set back a given distance from the coast according to actual or estimated sea level rise-as practiced by the State of Maine and described in more detail in volume 1, chapter 4-would not only allow room for wetlands to migrate, but could have the additional benefit of protecting or minimizing the loss of coastal buildings.

Option 4-16: *Identify* the *wetlands that are most able to migrate and sites to which they could migrate.* Identification of key areas for wetland migration in both coastal and riparian areas could be done through modifications of the various priority-setting mechanisms described below under "Improve Coordinated Management, Monitor-

29 Ibid.

30 Of course, even with sufficient land, the vegetation of wetlands may change from one type to another, Or some of the functions may be diminished, but without sufficient land for migration, loss of wetlands is guaranteed.

ing, and Research. " To date, none of these programs has included climate change considerations, although existing statutes would provide sufficient authority to do so. However, a congressional directive, perhaps with appropriations attached for the purchase of land for wetland migration, might ensure that agencies consider the need for land for migration.

Although accurate predictions of how climate change will affect wetlands and where they might migrate must await further research (outlined below), rough guesses of vital migration areas can be made now. EPA has already conducted several studies that combine various estimates of sea level rise with data on coastal topography and existing development to predict where coastal wetlands will be inundated (4, 52, 53, 73, 75). Periodic reassessments should be made as new information is obtained.

Option 4-17: *Acquire lands important for migration (including buffer zones). In the* absence of precise information on where wetland species might migrate, priority should be given to acquiring and protecting buffer zones around existing wetlands. This would be a logical first step in wetland protection. Buffers can help guard the present functions of wetlands, including flood control and the provision of wildlife habitat, and can also allow room for wetlands to grow in any direction in the event of climate change. Estimates of how far a buffer should extend from the wetland boundary vary, with a suggested range of 100 to 500 feet, depending on the area and the functions. Existing acquisition programs could be directed to incorporate suitable buffers with every purchase of wetlands or, at a minimum, with the purchase of wetlands most at risk from climate change.

A potential stumbling block is that acquisition programs focus on areas that are valuable now, rather than on those that could become valuable in the future. Although some areas important for future migration also have a high present value, such as the remaining coastal uplands in Florida, this may not be true of all sites. Setting priorities that balance a known present value with an uncertain future value would be quite difficult but could be accomplished through effective watershed-management plans, as discussed below and in volume 1, chapter 5.

Indirect *Federal Action*

Option 4-18: *Reduce Federal subsidies, such as Coastal Zone Management (CZM)funds and flood insurance, in areas that have not established setback or "planned-retreat" policies. The* State of Maine recently adopted, as part of its coastal-dune regulations, a rule known *as planned retreat,* which ''allows use of coastal property for constructing a building, provided the building is removed at some future time when the shoreline (high water line) has advanced to the building location" (86). Such planned-retreat policies are generally aimed at protecting coastal structures from costly damage, but these policies may also provide significant benefits for coastal wetlands. The Federal Government may best rely on State and local setbacks because land-use-control measures (such as zoning) generally lie within the purview of States or local areas. States' abilities to require or induce private-property owners to allow coastal wetlands to migrate with a rising sea, rather than to construct bulkheads, walls, and other structural protections, will hinge on the balance of private-property rights with the public-trust doctrine (which is rooted in case law and varies from State to State). However, the planned-retreat rule could be added to the Federal CZM program requirements, which explicitly mandate the protection of ecological values of coastal resources (including wetlands) and already cover issues such as beach protection and shoreline erosion. Of course, CZM cannot require States to take action, but it can offer a financial incentive.

Another way for the Federal Government to promote buffer zones is to eliminate funding for activities that encourage development in areas adjacent to wetlands or in floodplains (e.g., by using the COBRA approach as described in option 4-8). One potential weakness of the COBRA approach is that it addresses new construction and land uses. Existing activities, no matter how heavily subsidized by Federal programs in the past, are not covered by the act.

The Community Rating System (CRS) is a recent Federal Emergency Management Agency (FEMA) initiative that provides an incentive for communities to implement activities that exceed the minimum requirements of the National Flood Insurance Program (NFIP) (see vol. 1, ch. 4). Program participants can receive discounts in flood insurance premiums of up to 45 percent by promoting activities that protect floodplains and reduce flood losses. These activities include relocating structures at risk, removing debris from waterways, and preserving open space.

The CRS could be expanded to include the restoration of floodplains, which occupy a large part of the U.S. landscape and include many of the Nation's most productive wetlands and most fertile soil. Their functions include storing and conveying water, moderating floods, retarding erosion and sedimentation, maintaining water quality, recharging groundwater, and providing wildlife habitat. Under expansion of the program, credits could be given for actions that help to restore these functions.

Improve Coordinated Management, Monitoring, and Research

All three strategies presented above-protect existing wetlands, restore: degraded ones, and facilitate migration-will be more effective and efficient if applied within a regulatory and management framework that clearly identifies priorities and goals and that is coordinated across relevant programs and institutions to achieve those goals. This theme of coordination, which is important not just for wetlands but for all natural resources, is discussed in chapter 1; recommendations specific to wetlands, which can involve gradations from direct to indirect action, are described below.

Direct or Indirect Federal Action

Option 4-19: *Identify and assign priorities to the wetlands that are most important to protect and restore.* Identifying and ranking the wetlands that are the most important to protect now and in the future would help efforts to protect and restore wetlands. A listing of priorities that includes climate change considerations could be used to direct regulation, acquisition, and incentive programs throughout all levels of government. To be most effective, lists should be compiled for each major watershed and should be developed in consultation with all relevant stakeholders.

None of the Federal priority-setting mechanisms now used to direct wetland acquisition and restoration-the Land Acquisition Priority System (LAPS), the National Wetlands Priority Conservation Plan (NWPCP), the North American Waterfowl Management Plan (NAWMP), the Gap-Analysis Program (GAP) and the Coastwatch-Change Analysis Program (C-CAP--explicitly address the potential effects of climate change and its implications for setting priorities.

LAPS is a decisionmaking process used by FWS to set priorities for all of its land acquisitions, including wetlands. NWPCP, required by the Emergency Wetlands Resources Act of 1986, was developed by FWS to set criteria for identifying important wetlands to be acquired by Federal and State Governments. NAWMP, developed by FWS under the authority of the North American Wetlands Conservation Act of 1989, sets priorities for wetland conservation and restoration in the prairie-pothole region.

GAP is a land-use-analysis program at FWS that seeks to identify priorities for protecting endangered species. It addresses this and other goals by examining patterns of land use and ownership and comparing them with species habitat, vegetation, and other ecological features of the land (see ch. 5).

Run by the NOAA Estuarine Habitat Program, C-CAP provides information on the location, health, and loss rates of coastal habitats. To help set priorities for restoration, C-CAP has developed a standard protocol for rapid assessment of changes in habitat quality in coastal wetlands and the adjacent uplands.

These programs could be tied together and expanded for use in all Federal, State, and local efforts, including those involving regulatory, incentive, disincentive, acquisition, and restoration activities. In addition, they could be used to help identify indicators of climate change and methods of addressing these changes. Priorities could be reviewed periodically as new and more region-specific information on potential climate impacts is developed.

A potential problem with any general priority or ranking scheme for wetlands is that it assumes that the functions and products of different types are understood well enough to be compared and ranked accurately. Such schemes can easily fall prey to problems of focus and scale. For example, in coastal areas, FWS might need to evaluate whether top priority should be given to acquiring areas most at risk from sea level rise or to maintaining an interconnected network of lands. For inland wetlands, including riparian and depressional systems, it will also be important to identify water sources linked to the health of wetlands and to acquire water as well as land rights, where necessary.

Option 4-20: *Clarify national goals for wetland protection.* Climate change makes the need for clearly stated policy goals pressing. However, the Federal no-net-loss policy for wetlands is not clearly expressed in the regulatory framework, nor has it been completely embodied in Federal actions that provide incentives or disincentives to private activities that affect wetlands. Laws and programs should balance the need to preserve existing wetlands in the places where they are now with where they may or may not be in the future due to climate change.

One way to clarify wetland-protection goals is to use the opportunity offered by the upcoming reauthorization of the Clean Water Act to make its wetland-protection mandate explicit. Section 404 could be expanded, new sections could be added, or the focus of the entire statute could be changed from water quality to sustainable water use with watersheds. Another possibility would be to formulate a single new piece of legislation that would address wetlands specifically-a Federal omnibus wetland act. Some States have adopted such legislation. For example, Florida's Henderson Wetland Act of 1984 provides equal protection for all the State's waters and expands the State's jurisdiction over protection.

Option 4-21: *Ensure that Federal policies do not inadvertently lead to loss of wetlands.* Many Federal programs affect wetlands by encouraging different patterns of land use and development. The Emergency Wetlands Resources Act of 1986 called for the Department of the Interior (DOI) to conduct and publish a comprehensive review of the impacts of Federal programs on wetlands. One part of that review has been completed and released (102), but the second volume has yet to be published. Volume I discusses the lower Mississippi alluvial plain and prairie potholes. Volume II was to include: the Everglades, coastal Louisiana, Galveston Bay, Puerto Rico, California's Central Valley, western riparian areas, and Alaska. DOI should be urged to complete and issue Volume II promptly. Once the review is available, Congress may wish to consider amending programs that conflict with protection.

Option 4-22: *Promote integrated resource management at the watershed level.* Greater coordination and integration of programs and institutions would allow more-efficient management of wetlands. The Federal Government should explore ways to institute watershed-based management programs that would consider wetlands along with other natural resources. There is currently a great deal of interest in watershed management, and S. 1114, the Water Pollution Prevention and Control Act of 1993, contains a major section promoting it. Watershed management essentially recognizes that the many uses of water are tied together and that problems and their solutions are most effectively considered on a system-wide basis.

Managing wetlands within a watershed context would require an improved understanding of the types and amount of wetlands needed within any given watershed to support ecological functions and to maintain the entire system in a healthy state. This approach would require inventories of land, water, and wetlands so that models can be developed for estimating how changes in some parts of the system (whether caused by climate or by human activity) would affect functions elsewhere.

Many efforts already exist that could form part of an integrated management program, and numerous studies have recommended the need for such an approach (see ch. 1 and vol. 1, ch. 5). Programs with some form of integrated planning have been attempted in States including California, Florida, Georgia, Oregon, and Massachusetts. These programs should be reviewed so that any Federal action would complement-and avoid inadvertent interference with-successful programs at the State level.

Option 4-23: Use legislative *reauthorizations to integrate preservation and restoration. The* Clean Water Act and, to a lesser extent, the Endangered Species Act (P.L. 93-205) are vital elements of national wetland policies. Both are up for reauthorization. The controversy surrounding the Clean Water Act stems partially from the lack of consensus about what the wetland mandate should be. Also, the effectiveness of the species-by-species approach used in the Endangered Species Act has been questioned by critics as well as by some who fully support its goals. Reauthorization offers an opportunity to explore new ways to protect and restore biodiversity and ecosystems, both in wetlands and elsewhere.

Under the Clean Water Act, pilot projects in watershed management could be initiated in small watersheds where wetlands are either threatened or already degraded. Wetland-restoration projects could be systematically monitored and evaluated to explore whether restoration techniques can rejuvenate a full range of wetland functions and support the original diversity of flora and fauna in addition to accomplishing more case-specific goals, such as providing habitat for waterfowl.

Option 4-24: *Support long-term research and monitoring on the impacts of climate change on wetlands.* Efforts to identify which lands will be most valuable as the climate changes-and, in particular, estimating where migration of wetlands might occur-face a daunting lack of detailed regional climate predictions and a poor theoretical understanding of how climate and other hydrological and ecological changes will affect wetlands. Key areas of investigation that are needed include:

- establishing a baseline of wetland conditions nationwide and a long-term monitoring network to document rates and types of change;
- assessing how wetlands have already been altered in areas where the water regime has changed in ways similar to those predicted for climate change;
- determining g water needs for healthy wetlands and the hydrological connections between wetlands and groundwater;
- evaluating salt movement through estuaries, coastal aquifers, and inland surface- and groundwater systems;
- researching the adaptability of key wetland species (both plants and animals);
- assessing how extreme events such as storms and droughts affect the functioning of wetlands; and
- developing and evaluating restoration and creation technologies.

Some of these topics are already the focus of research efforts at the Fish and Wildlife Service's National Wetlands Research Center and the Army Corps of Engineer's Wetlands Research Program at the Corp's Waterways Experiment Station in Vicksburg, Mississippi. EPA's Environmental Monitoring and Assessment Program has also proposed monitoring some pertinent indicators of the condition of wetlands. The NBS (see ch. 5) could also incorporate wetland assessment into its broader mandate.

FIRST STEPS

This chapter has described how the current policies for protecting wetlands in the United States fall short of meeting the stated no-net-loss policy goal. Because climate change will exacerbate existing stresses on wetlands as sea level rises in coastal areas and as some interior wetlands dry out, the problems encountered under current wetland-protection policies will become more acute. Thus, policies designed to facilitate adaptation of wetlands in the future must, at a minimum, seek to accomplish four goals:

1. establish a clear national policy for wetland protection,
2. integrate protection across agencies and across other natural resources,
3. establish and implement a priority plan for acquisition and protection, and
4. enhance protection of especially vulnerable wetlands.

The Federal Government cannot use all policy tools to address these problems with equal assurance of success. Because 74 percent of all wetlands are on privately owned lands, the potential for direct Federal intervention is limited. Given the available policy levers (regulation, acquisition, incentives, and research), the limited funds for programs, and the level of scientific understanding of the impacts of climate change on wetlands, OTA has identified the following strategies as potential “frost steps” to respond to climate change and the threats it poses to wetlands. This list comprises policies that should be initiated based on concerns about climate change now.

- Revise **the** Clean Water Act. The Clean Water Act (CWA), which is up for reauthorization, could be revised in various ways to improve the protection of wetlands. The absence of a clear and explicit mandate hampers wetland protection. Regulatory activity under Section 404, for example, is limited because of ambiguity about its applicability to wetlands that are periodically inundated or saturated-rather than wet all year. Furthermore, because existing statutory language emphasizes only the protection of surface-water quality, drainage activity that may destroy wetlands is not regulated unless it results in the discharge of materials into protected waters. Congress could revise the statutory language of CWA to spell out a clear goal of protecting wetlands and to extend regulation to all activities that destroy wetlands. A bill introduced during the 103d Congress, S. 1304, proposes revisions along these lines.

  Another potential target for revision is the provision for mitigation banking. If properly managed, regionally coordinated mitigation projects could offer both greater regulatory flexibility and more-effective restoration within watersheds. CWA could be modified to establish uniform standards for mitigation activity and to require that activities be comprehensively monitored and evaluated for success. Success should be determined by the restoration of the destroyed wetland’s unique function and value as well as at least equivalent lost-wetland area.

  The act could also be expanded to promote comprehensive watershed management. Regional watershed management could be fostered by revising CWA to set up coordinating mechanisms and incentives. Wetland protection and restoration could be linked to regulations covering non-point-source pollution to create a more integrated approach to achieving mandatory water-quality levels. The bills now under consideration include a watershed-management component, but the key will be to ensure that wetlands are incorporated into this broader water-quality framework.

- Develop and implement priority plans to coordinate wetland protection across agencies. Federal agencies including the Fish and Wildlife Service (FWS), the Environmental Protection Agency (EPA), the Army Corps of Engineers (Corps), and the U.S. Department of Agriculture (USDA) have developed different methods for making decisions about wetland protection. Methods for monitoring, delineating, and assigning priority for acquisition or restoration vary according to the particular goals and responsibilities of each agency. These differences have led to enormous actual and perceived disparities in the protection of wetlands.,

  The various Federal agencies (e.g., the Corps, EPA, FWS, and USDA) should coordinate the designation of wetlands that are deemed to be high priority for protection, restoration, or acquisition. Development of regional priority plans and oversight of their implementation could be supervised by a multiagency task force composed of representatives from all Federal agencies that have responsibilities for wetlands. Alternatively, the White I-louse Office of Environmental Policy (OEP) could provide coordination and oversight. Once in place, Federal agencies could be directed to use this uniform priority plan in making decisions on CWA Section 404 permitting, land acquisition, easements, and restoration (through Swampbuster, Wetlands Reserve, and other programs). Such a plan should be updated periodically to reflect changing circumstances, including the anticipated effects of climate change.
- Ensure that Federal policies and incentives are consistent with wetland protection. Although Executive Order 11990, issued in 1977, directs Federal agencies to consider how their policies will affect wetlands, there are still many opportunities to revise existing Federal programs to enhance wetland protection.

Congress should urge the Fish and Wildlife Service to complete its review of the impact of Federal programs on wetlands that was mandated by the 1986 Emergency Wetlands Resources Act. Prompt completion of the report could assist further efforts to identify programs that could be modified to reduce their impacts on wetlands.

Even without the review, some programs appear to be prime candidates for modification. For example, Congress could amend the Coastal Barrier Resources Act to expand its coverage to include a broad range of coastal wetlands. Extending the act would not only help protect wetlands, but would also reduce Federal expenditures and, by slowing development in high-hazard coastal areas, could cut down on damage to human lives and property during coastal storms. Congress could also act to increase incentives to private landowners to set aside and restore wetlands. For example, Congress could maintain full funding for the Wetlands Reserve Program in future appropriations. Tax benefits for landowners who grant conservation easements on or make outright donations of wetlands to Federal, State, or local conservation organizations could be increased, as called for in H.R. 2149 (102d Congress).

Increased coordination across Federal programs could also promote wetland protection. Wetlands could be included among the issues considered in the Western Water Policy Review enacted by the 102d Congress (see vol. 1, ch. 5), perhaps considering ways to link conservation of riparian wetlands to measures promoting water-use efficiency. Agencies should be urged to take full advantage of the Farmers Home Administration (FmHA) Conservation Easement Program to review lands under FmHA loan defaults and to acquire title or easements to high-priority wetlands. Similarly, lands on decommissioned military bases should be reviewed for their value for acquisition or restoration as protected wetlands.

- Conduct research, development, and evaluation in key areas. Research and monitoring should be part of any long-term effort to protect and restore wetlands, now and as the climate changes. Congress could encourage agencies to incorporate research on wetlands into their U.S. Global Change Research Progam efforts (see ch. 3). Congress could also direct the Department of the Interior to include an assessment of wetlands and periodic monitoring for the effects of climate change in the proposed National Biological Survey (see ch. 5).

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WETLANDS-FIRST STEPS

- Revise the Clean Water Act
  - -Make the *wetland* protection mandate specific in Section 404 or elsewhere.
  - -Ensure that more land is set aside for protection or restoration than is destroyed.
  - -Establish uniform standards for mitigation activities.
- Develop and implement priority plans to coordinate wetland protection across agencies
  - -Build on existing plans under various agencies (i.e., the U.S. Army Corps of Engineers, the Fish and Wildlife Service, the Environmental Protection Agency, and the U.S. Department of Agriculture).
  - —Direct agencies to use the priority plan in issuing permits (under Section 404 of the Clean Water Act) and acquiring land and easements (through the Swampbuster and wetlands Reserve Program and other programs).
  - -Coordinate planning and management for wetlands at the watershed level.
- Ensure that ail Federal policies and incentives are consistent with wetland protection
  - —Extend the Coastal Barrier Resources Act to include coastal wetlands.
  - —Require the Fish and Wildlife service to issue Volue 2 of *The Impact of Federal Programs* a report mandated in the 1986 Emergency wetlands Resources Act.
  - -Restore the wetlands Reserve Program at least to authorized levels; target wetlands in high-priority areas.
  - —Restore tax incentives to private landowners who grant conservation easements.

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Preserves: Federally Protected Natural Areas 5

Status

- Represent and protect the best of the Nation's natural heritage.
- Repository for the Nation's rarest species and for conserving biodiversity.
- Threatened by human activity.

The Climate Change Problem

- A shifting climate ''map' over protected areas with fixed boundaries.

What Is Most Vulnerable?

- Areas that are small, isolated, fragmented, under other stress.
- Areas containing climate-sensitive species or ecosystems.
- Some biodiversity loss likely.

Impediments

- Many levels of institutional and landscape fragmentation.
- Lack of knowledge.

Types of Responses

- Ideal responses (if we had the information): 1) maintain species and/or ecosystems "in place"; 2) help them move.
- Realistic responses (given gaps in our knowledge): 1) acquire needed information (basic research, inventorying, monitoring); 2) manage the areas to minimize impediments to adaptation and to increase resiliency of natural areas (through direct Federal action, indirect Federal action, partnerships).

OVERVIEW

Setting aside large areas of land to protect their natural qualities and processes has become a central strategy in preserving the American heritage. As long ago as the early 1800s, prominent American writers and artists envisioned the preservation of parts of the wild, undeveloped frontier and voiced their concern about the destructive effects of western expansion. The establishment of Yellowstone National Park in 1872 marked the beginning of putting these ideals into practice (157). Since then, the Federal Government has established several systems of reserved lands (e.g., the National Parks, the National Wilderness Preservation System, and National Wildlife Refuges) and special management agencies (e.g., the National Park Service and the Fish and Wildlife Service) to administer and protect valued resources (see box 5-A).[1] Federally protected natural areas have become a repository for the Nation's rarest species and for conserving biological diversity. Over 240 million acres (97 million hectares)[2] are now held by the Federal Government specifically to ensure the protection of wildlife, aesthetic beauty, or other natural attributes for the enjoyment of future generations. Nearly $3 billion is spent annually to manage, maintain, restore, and protect these lands. Climate change may threaten this substantial national investment in protecting natural areas.

Projected rates of climate change are faster than any that have occurred on a global scale over the past 10,000 years-since the last ice age (57). Climate regimes could shift dramatically.[3] Whether plants and animals accustomed to a particular climate regime will be able to adjust to climate change is uncertain (see ch. 2). The opportunities for species to respond by migrating or adapting may be limited; species in small, isolated, fragmented areas may be particularly at risk. The climate "map" that has helped shape the distinctive vegetation and wildlife of many reserves will shift, while the boundaries of the protected areas remain freed. Some reserves may be ''left behind," incapable of providing the benefits or serving the functions for which they were originally established, such as providing protection for rare species or supporting wildlife-related recreation (see fig. 5-l). It may become too costly or impossible to protect certain species. To protect other plant and animal species, land-management agencies might find it necessary to undertake increasingly aggressive approaches to management (see box 5-B).

To compound the problems, many natural areas have already become threatened by forces within and outside their boundaries. Population growth has led to development pressures, growing visitor use, and increased geographic fragmentation of natural areas. Institutional fragmentation, with the management structure governing Federal lands dispersed across several agencies and having no unifying goal, has in some cases also compromised preservation efforts. Boundaries of protected areas are somewhat artificially fixed, with many surrounded by actively managed or developed lands. With growing fragmentation, it will be increasingly difficult for natural areas to adapt to the stresses of climate change.

Given the vast amount of uncertainty surrounding climate change and natural area responses, the most sensible ways to prepare for climate change in federally protected natural areas today are to: 1) improve information gathering, and 2) enhance protection of federally protected areas and their resources.

1 The National Wilderness Preservation System is administered by four Federal agencies: the U.S. Department of Agriculture's Forest Service and the Department of the Interior's Bureau of Land Management, National Park Service, and Fish and Wildlife Service.

2 To convert acres to hectares, multiply by 0.405.

3 A warming of 5.4 °F (3 °C) over the next century would shift climatic regimes perhaps 200 to 300 miles (300 to 500 kilometers) northward or 1,600 feet (500 meters) in elevation (58, 96, 172).

Box 5A-Climate Change and Management Philosophies for Natural Area Management

National Park System-Recent National Park Service (NPS) policies state that managers should seek to "maintain all the components and processes of natural evolving ecosystems, including the natural abundance, diversity, and ecological integrity of the plants and animals" (151). Although "change is recognized as an integral component of the functioning of natural ecosystems," NPS policies regarding wildlife and plant protection are based on the assumption that climate is relatively static or at least slow to change. The changes currently protected under NPS policies imply "natural," including evolutionary, changes--not necessarily the rapid changes predicted for human-induced climate change. Stated policies may encourage resisting migration and other adaptive responses and maintaining only the existing species that now occur inside National Park boundaries. This goal may be difficult to attain under climate change as wildlife and plants attempt to migrate. On the other hand, if human-induced climate change is seen as a natural phenomenon, management of National Parks may tend to accommodate species shifts.

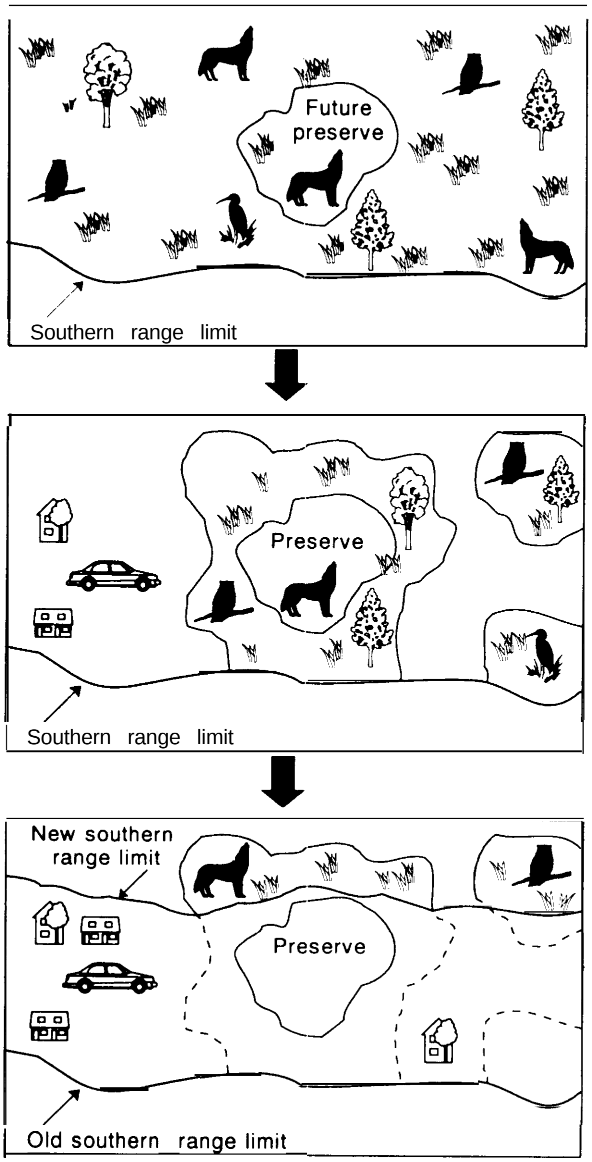
National Wildlife Refuge System--Climate change may pose a problem for refuge management because efforts to protect waterfowl and other species may require even more intensive and costly management than they do today. The ability to protect species maybe greater for National Wildlife Refuges than for National Parks because more intensive manipulation of habitat is allowed. Most refuges were established to protect waterfowl habitat, flyways, and breeding grounds (6, 125), which explains why roughly one-third of wildlife refuges are wetlands. Furthermore, refuge habitat and wildlife are often manipulated to meet production targets, such as waterfowl population quotas (6, 144). Over 30 refuges were established to protect threatened and endangered species, and their management is designed to protect those species--not necessarily to maintain the naturalness of the area (144). Recent additions to the system, such as those added under the Alaska National Interest Lands Conservation Act (P.L. 96-467), seek to "conserve fish and wildlife populations and habitats in their natural diversity," signaling a more hands-off approach to management (6). In addition, the Fish and Wildlife Service is currently reviewing the management philosophy for the entire System, and is advocating more emphasis on multispecies and ecosystem-level management (1 51).[1]

National Wilderness Preservation System-For most wilderness areas today, changes that occur as a result of human-induced climate change maybe consistent with maintaining the "wilderness character" of the area if climate change is perceived as a natural phenomenon. However, allowing those changes may prevent wilderness areas from offering high quality habitat or protection for rare or endangered species. Under the Wilderness Act (P.L. 66-577), all agencies that administer Wilderness Areas are directed to "preserve the wilderness character" of the area for future generations. Generally, a "hands-off" approach to management is followed when possible, and natural processes are allowed to govern with minimal human interference. Extreme threats of fire, insects, or disease can be controlled by using the "minimum tool necessary" to accomplish the task-as defined by the courts-so that wilderness values are minimally damaged (129, 139). If climate change is perceived as a human-caused disruption of natural processes, it is not dear how management would change. Changes in wilderness areas caused by human-induced climate change maybe interpreted as changes in the wilderness character of the area. If so, more active management to minimize these changes might be justified.

1 **Because** no law mandates an overarching direction for the Refuge System, this new management philosophy may conflict with the legislatlve objectivesforwhich an individual refuge was established and, if so, would become subordinate to those objectives.

SOURCE: Office of Technology Assessment, 1993.

Figure 5-l-Preserves and Climate Change



NOTE: As climate regimes change, species may migrate, decline, or become extinct, leaving preserves dramatically changed. Migrating species may find it difficult to find new habitat and may no longer be protected.

SOURCE: Office of Technology Assessment, 1993,

Additional research and monitoring are essential for informed decisionmaking about natural areas in a changing climate. Information is needed to help direct efforts in the acquisition of natural areas, to determine the sensitivity of species to climate, to restore damaged natural areas to ecological productivity, and to anticipate and respond to environmental hazards (85). To even identify the effects of a changing climate, baseline data on current ecosystem structure and functions are needed.

Enhancing the protection of federally protected areas that makes them more resilient to climate change and more able to confront existing stresses can be achieved in numerous ways. Direct Federal mechanisms, such as acquisition programs and agency management could be tailored to better protect natural areas by enlarging or joining existing areas, for example. Indirect Federal actions, including the suite of incentive and cost-sharing programs for private land management, could also be tailored to help buffer and protect natural areas. Partnerships among Federal, State, local, and tribal governments as well as private organizations and interest groups could be more aggressively pursued as a way to augment Federal natural area protection efforts.

Increasingly, land managers and scientists are calling for a more holistic approach to land management that is based on ecosystem, topographic, or watershed boundaries. For example, in 1992, the Forest Service and the Bureau of Land Management (BLM) announced policies that would place greater emphasis on total ecosystem management. Although this new approach is not yet well-defined, it is generally understood to include planning that transcends ownership boundaries and that requires active cooperation between multiple agencies, governments, and interest groups. Some see this new approach as the beginning of a fundamental change in the way the Nation protects its resources and, to the extent that landscape and institutional fragmentation are reduced, an effective approach to helping some protected areas adapt to climate change (13, 75, 96).

Box 5-B-The Strategic Dilemma for Protecting Natural Areas Under Climate Change

To minimize Ioss of the investment in natural areas and their resources, Federal agendas may ultimately need to change their management approach to one that runs counter to currently prevailing approaches. Because climate change may tend to change the composition of animals and vegetation in natural areas, management policies that seek to protect the status quo at any cost as well as those that allow unlimited change will be called into question. The "moving map" imposed by climate change will make each type of management scheme more difficult to implement- Current philosophies are based on a relatively constant mean climate. Climate change will shift this mean climate with year-to-year weather variations. Climate change will shift this mean. Subsequent changes in natural resources and processes might not be easily addressed under management strategies that are based on the assumption of a relatively static climate.

Areas valued for their ecological processes may require more manipulation and intensive management to save valued resources. Agencies may have to develop contingency plans to facilitate change in management direction when necessary. Three very general approaches to natural area protection are possible under climate change: 1) maintain existing species composition, 2) maintain some species in place and allow change for others, and 3) allow climate change impacts to occur.

Strategy 1: Maximize efforts to preserve current species composition-No management scheme governing Federal protected natural areas fully embraces this philosophy, although management of the National Park System in the 1960s advocated this approach. NPS policies were influenced by the 1963 Leopold Report, which suggested that the overriding goal for National Park management should be to preserve "pre-settlement" pristine conditions (88, 172). Hence, management policies favored protection of species historically living in the park and directed active restoration of areas damnaged by''post-settlement" activities. Although emphasis is still on maintaining the historical mix of species in National Parks, most recent National Park Service (NPS) policies also seek to protect evolutionary change and shifting natural processes. The overall goal is to maintain a healthy ecosystem.

Maintaining the status quo may be important for protecting rare species and communities and for maintaining biodiversity now. However, climate changes of the rate and magnitude predicted by scientists could cause changes in vegetation and species mixes that would make maintaining historical communities increasingly difficult and costly. Such preservation efforts may run counter to natural processes that are pushing for ecosystem change. Because of new developments in the scientific understanding of ecological communities, this strategy is currently being questioned even without considerations of climate change (88, 104).

To implement this strategy under climate change, more hands-on, intensive management will be required to stave off nonnative or opportunistic species invasions, fight unnatural pests and disease, and possibly prevent fires. Given the Nation's experience with protecting endangered species, the costs of preserving entire ecosystems by similar "brute force" will likely become prohibitive. Thresholds might have to be set to determine when to terminate preservation efforts for some areas. To best manage resources under this strategy, research efforts should focus on understanding how communities interact with-each other, respond to stress, and adapt to change.

Strategy 2: Preserve some species in place and allow change for others--Although this is not an official management strategy for any Federal land-management agency today, it is by default the primary method of management in National Wildlife Refuges. A National Midlife Refuge is generally managed to preserve a specific community or species so management may allow change in other resources as long as the primary refuge objective is not adversely affected. In addition, areas that contain endangered species are required by the Endangered Species Act {P.L 93-205) to provide protection for these species despite other management objectives. Still, the costs of protection for even a single species can be extremely high (see box 5-Don the expenditures of endangered species recovery programs).

To implement this strategy in the future, research will be needed to identify what species should or can be protected in an evolving habitat and which species could migrate. For migrating species, corridor theory and design

(Continued on next page)

Box 5-B–The Strategic Dilemma for Protecting Natural Areas-(Continued)

techniques will need to be developed further, as will techniques for translocation of species. The current understanding of ecosystem structure and function will have to be greatly expanded Again, thresholds for when to intensify or abandon preservation efforts might have to be established to facilitate future management decisions.

Strategy 3: Allow climate change impacts to occur—This strategy represents a completely “hands-off’ policy. Although it is not an official policy for natural area management, minimal human intervention with natural processes is an ideal goal advocated by the Wilderness Act (P.L. 66-577) and by some NPS policies. In practice, however, managers must intervene with natural processes to minimize damage from human activities (e.g., pollution and visitor use) and to simulate other processes (e.g., the natural fire regime).

Under this strategy, climate impacts would be seen as simply changing the composition of the landscape in a natural way. Extinctions and changing species composition would bean adaptation in and of itself. This may bean appropriate approach for areas that are not valued for a specific species or community mix and that are large enough to accommodate a wide range of natural processes. Because so little is known about how ecosystems work, this approach is favored by some experts as the best adaptive strategy for many species under climate change (13, 51, 69, 98).

However, if climate change accelerates weed, disease, and pathogen spread, a “hands-off” approach could result in serious conflicts with adjacent landowners. In addition, t his strategy offers the least active protection for rare and endangered species. Public and political pressure may lead to intervention with natural processes. To maintain the maximum amount of existing species and biodiversity while embracing this approach, new natural areas with diverse species compositions may need to be established. Given the level of fragmentation and development, especially in the East, there are few opportunities to establish new natural areas of sufficient size to sustain large ecosystems. Much more information about reserve design, size, and connectivity will be needed to effectively establish new natural areas,

SOURCE: Office of Technology Assessment, 1993.

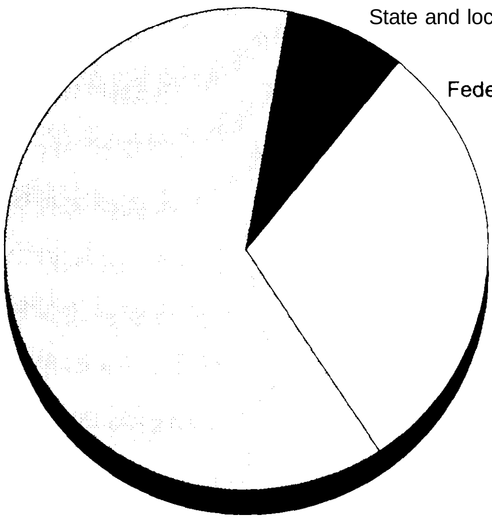
FEDERALLY PROTECTED NATURAL AREAS TODAY

• What Are Federally Protected Natural Areas?

Many lands under various Federal management designations as well as substantial amounts of private- and State-owned land are more or less in a “natural’ state (primarily governed by nature). In addition to conserving natural processes, these areas can provide: protection for fish and wildlife species and their habitat, a haven for endangered and threatened plant and animal species, and unique opportunities for certain kinds of recreation including wildlife watching, nature study, photography, hiking, and camping. In this sense, millions of acres of U.S. lands (including Federal, State, tribal, and private lands), some of which are as pristine as some designated Wilderness Areas, can be considered *natural areas.*

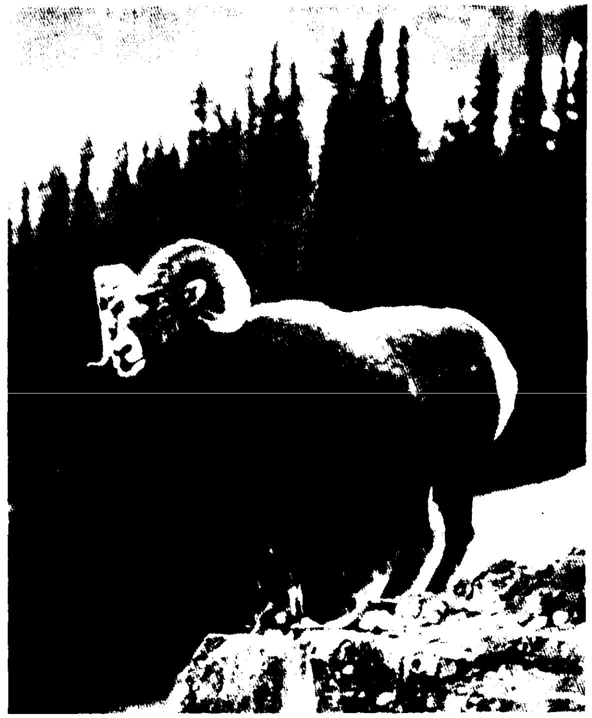
About one-third of the Nation’s land base is held by the Federal Government and administered by several different agencies (see fig. 5-2). Although much of this land is essentially “natural,’ its management varies. Some lands are managed explicitly to retain relatively pristine conditions by limiting human use and development and focusing on preserving the natural processes that have shaped the landscape. Examples of the lands under Federal ownership include National Parks, administered by the Department of the Interior’s (DOI’S) National Park Service (NPS), and units of the National Wilderness Preservation System, administered by the U.S. Department of Agriculture’s (USDA’s) Forest Service, BLM, the National Park Service, and

Figure 5-2-Landownership of the U.S. Land Base



SOURCE: Congressional Research Service, 1990.

DOI's Fish and Wildlife Service (FWS). Some lands axe managed to provide for a variety of uses (multiple-use lands), including some resource use and development that may alter natural processes, and conservation of natural qualities and processes such as wildlife habitat and watershed protection. Examples of federally held lands managed for multiple uses include 151 million acres of the National Forest System[4] administered by the Forest Service and 236 million acres administered by BLM.[5] Other lands are managed primarily to provide for a single purpose, such as the protection of a specific species or ecosystem. Many National Wildlife Refuges (NWRS), administered by the Fish and Wildlife Service, are in this category. Lands managed to protect a single species, such as some National Wildlife Refuges, are often so intensively managed for that purpose that they may not strictly be considered natural areas.



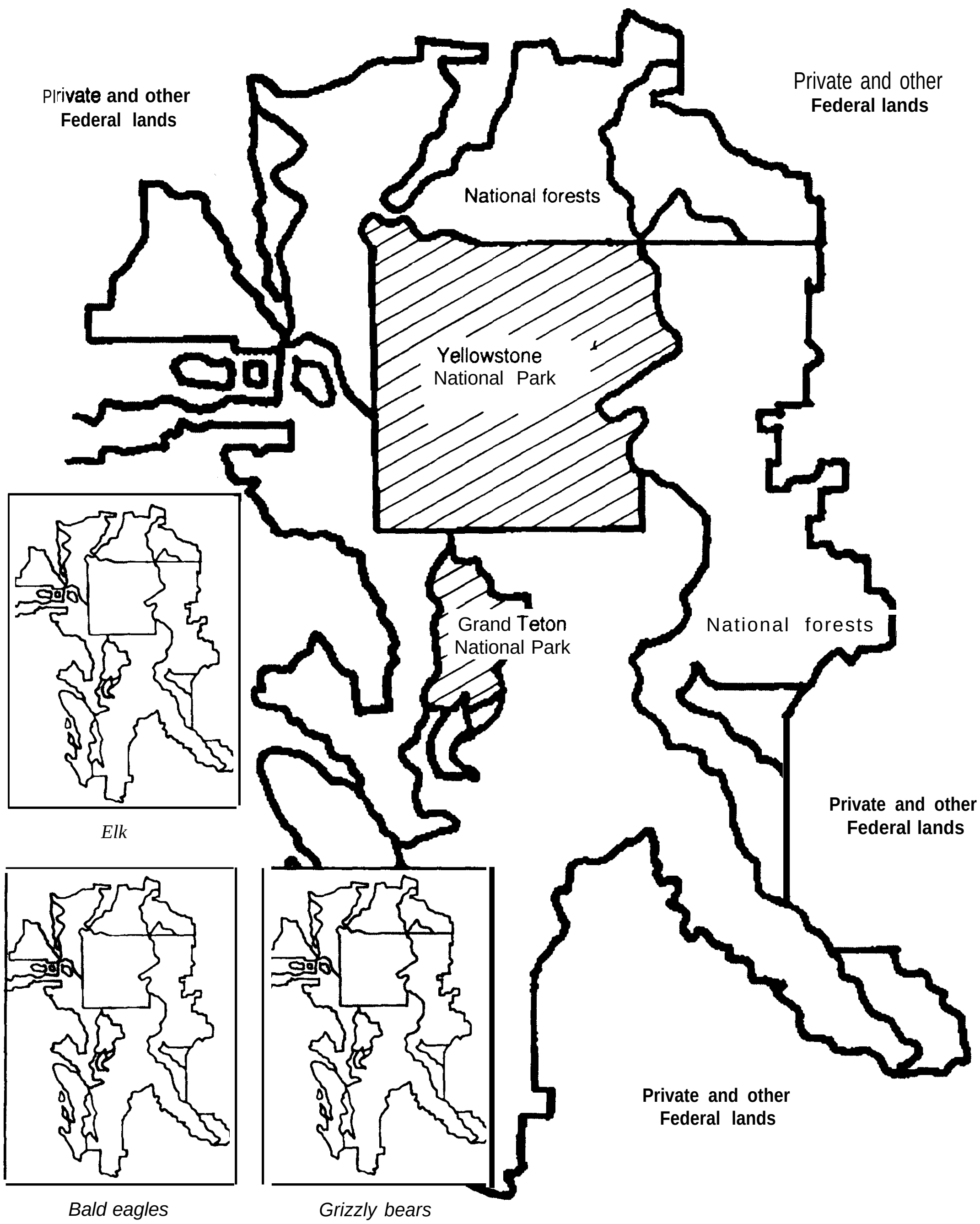
Bighorn sheep require large expanses of alpine habitat for survival. Wilderness areas provide sources of food and cover that they and other wide-ranging species-such as bear, caribou, and coyote--rely on.

Many species require large areas of suitable habitat-often much larger than contained in any one management area—to sustain a healthy population over the long term. Most natural areas with special Federal protection are too small to sustain whole ecosystems for larger species such as grizzly bears, grey wolves, and the Florida panther (29). Habitat for some species, such as migratory birds and salmon, may span several States. Thus, multiple, connected land parcels under various management regimes and ownerships may be critical habitat for certain species. Figure 5-3 illustrates the importance of surrounding lands for elk, eagles, and grizzly bears in

[4] The National Forest System includes 191 million acres, 40 million of which are set aside for Wilderness Areas, Wild and Scenic River areas, primitive areas, scenic research areas, recreation areas, game refuges, wildlife preserves, and monument areas and are therefore not included in the multiple-use management plans (2).

[5] BLM administers 269 million acres, 33 million of which are set aside for areas of critical environmental concern, research natural areas, outstanding natural areas, national natural landmarks, wilderness study areas, and wilderness lands.

Figure 5-3—Habitat Needs of Elk, Eagles, and Grizzly Bears in the Greater Yellowstone Ecosystem



SOURCES: Office of Technology Assessment, 1993; Greater Yellowstone Coordinating Committee, ***The Greater Yellowstone Area: An Aggregation of National Park and National Forest Management Plans*** (Washington, DC: U.S. Department of the Interior, National Park Service, and the U.S. Department of Agriculture, Forest Service, 1987).

Yellowstone National Park. Increased recognition of the importance of large land areas in maintaining natural processes and the species that depend on them has led to the development of a new management concept called *ecosystem management.* Although no one clear definition of this new kind of management has emerged, it generally refers to an attempt to view and manage natural processes on a larger scale. The Forest Service defines ecosystem management as promoting "diversity, productivity, habitat for wildlife, and longterm sustainability" (135).

Although all natural areas (public and private) are important for protecting the Nation's natural heritage, this chapter will focus primarily on federally protected natural areas —lands set aside by the Federal Government specifically for protecting unique natural characteristics or processes.[6] National Parks, National Wildlife Refuges, and Wilderness Areas compose the bulk of Federal lands under special Federal protection. Table 5-1 lists the numerous Federal designations for protected natural areas in the United States. And box 5-C broadly outlines the 'policy space''—the existing institutions, legislation, and regulations-for Federal natural areas.

Current Distribution

The Federal Government has set aside about 71 million acres as protected natural areas (National Parks, Wildlife Refuges, and Wilderness Areas) in the lower 49 States, not including multiple-use lands such as National Forests, and an additional 180 million acres of protected lands in Alaska (see table 5-2).[7] These Federal holdings represent a range of land types that includes tundra, wetlands, forests, alpine areas, deserts, grasslands, and seashores. In the continental United States, the largest federally protected areas are located in the Western States, on the coasts, and in Alaska. There are also numerous, small protected natural areas in the East. Wilderness Areas comprise the largest single system of protected natural areas in the continental United States, with over 80 percent of their 35 million acres located in the 11 Western States. Most of the 23 million acres of the National Park System in the continental United States is also located in the West. The 13.4 million acres of National Wildlife Refuges in the continental United States are generally located along the major flyways of migratory birds: eastern coasts and waterways, the Great Plains, and desert areas of the West. Figure 5-4 shows the geographical distribution of federally designated natural areas and agency jurisdiction.

Table 5-l—National Parks, Wildlife Refuges, and Wilderness Areas in the United States

Official designation	Number of sites	Area in acres[a]
National Parks[b]	49	47,240,000
National Wildlife Refuges	424	89,900,000
National Wilderness Areas	457	87,480,000
U.S. Forest Service	332	31,000,000
Bureau of Land Management	22	370,000
National Park Service	38	36,780,000
Fish and Wildlife Service	65	19,330,000

a To convert acres to hectares, multiply by 0.405.
b National Park acreage does not include all lands administered by NPS (e.g., National Monuments). See box 5-C for further explanation.

SOURCE: Keystone Center, *Biological Diversity on Federal Lands,* report of a Keystone Policy Dialogue (Keystone, CO: Keystone Center, April 1991); U.S. Congress, Office of Technology Assessment, *Technologies to Maintain Biological Diversity,* OTA-F-30, (Washington, DC: U.S. Government Printing Office, March 1987).

6 This is a distinction made by political ownership systems-not by the quality of the land under them.

7 To avoid "double counting" of areas with more than one designation these figures include acreage of all lands managed by the National Park Service and the Fish and Wildlife Service (although a small amount of NPS lands is protected as historic sites and battlefields), plus acreage designated as Wilderness administered by *other* agencies (the Forest Service and the Bureau of Land Management). These figures may differ from those in table 5-2 because the protected areas listed there may occur under more than one designation. For example, acreage for the National Wilderness Preservation System cited in the table includes wilderness acreage located in the National Park System and the National Wildlife Refuge System.

Box 5-C-Federally Protected Natural Areas: The Legislative Framework

The National Park System–The National Park System is administered by the National Park Service (NPS) in the Department of the Interior (DOI). It comprises several units[1] totaling 76 million acres (31 million hectares).[2] Twenty-two official designations are used to group these units, and each designation reflects the primary purpose for which the unit was created. Designations include National Parks, National Monuments, National Preserves, National Lakeshore, National Seashores, and National Battlefields. The laws establishing some NPS units explicitly encourage economic development near the park and allow heavy resource use, such as off-road-vehicle use and oil development, while other NPS units possess legislative mandates t hat are more strict than those for Wilderness Areas. Over half of the acreage of the National Park System is contained in National Parks, and over 80 percent of total NPS acreage is under designations designed to protect the naturalness of the area.

To achieve some management consistency, the National Park Service has grouped all units, regardless of designation, into one of four management categories: *natural zones, cultural zones, park development zones,* and special use zones.[3] Natural zones are managed to conserve natural resources and ecological processes while allowing visitor use.

All NPS units are joined by the National Park Service Organic Act of 1916 (16 U.S. Code (U.S. C.) Sec. 1-4,22,43), which spells out the mission of the National Park Service: to "conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of t he same in such manner and by such means that will leave them unimpaired for future generations." This directive sets up a dual and sometimes conflicting mission for NPS-to conserve and preserve park resources and to provide for public enjoyment.

The National Wildlife Refuge System (NWRS)-The 91 million-acre NWRS is administered by the Fish and Wildlife Service (FWS) in DOI to "provide, preserve, restore and manage a national network of lands and waters sufficient in size, diversity, and location to meet society's needs for areas where the widest possible spectrum of benefits associated with widlife and wiidlands is enhanced and made available" (147). Although the refuges are administered by the Fish and Wilddlife Service, management of each one is largely guided by the legislation that established it; thus, management varies widely among refuges. Early refuges were created as inviolate sanctuaries to protect waterfowl and migratory birds under the Migratory Bird Treaty Act (16 U.S.C. Sec. 703-708,709a,710,711) and the Migratory Bird Conservation Act (16 U.S.C. Sec. 715-715r). Although waterfowl protection is still the major thrust of NWRS management, later refuges were created specifically to protect endangered species, and the most recent additions aim to protect multiple species and ecosystems (148). Because management of most refuges is aimed at protecting specific species, the habitat is often intensively managed and manipulated. in addition, under the Refuge Recreation Act of 1962 (P.L. 87-714 et seq.) and the National Wildlife Refuge System Administration Act of 1966 (P.L. 91-135 et suppl.), economic and recreational uses such as oil and gas leasing, logging, grazing, haying, hunting, and fishing maybe permitted and encouraged if such activities are deemed "compatible" with the purposes of the refuge.

To commemorate the IOOth anniversary of the first wildlife refuge (Pelican Island, FL, in 1903), the Fish and Wildlife Service began preparing Refuges 2003, *A Plan for the* Future to address management issues facing the system. This planning process has identified seven possible management directions from strict protection to more emphasis on multiple use. In the most recent draft, the Fish and Wildilfe Service is advocating a "balanced" option, which would put greater emphasis on ecosystem management and wildlife-oriented uses for the system (151).

1 A "unit' refers to any area or parcel of land in the National Park System. For example, any given National Park National Seashore, or National Monument is a unit of the National Park System.

2 To convert acres to hectares, multiply by 0.405.

3 Cultural zones are managed for the "preservation, protection, and interpretation of cultural resources and their settings" while providing for pubilc use and enjoyment. Park development zones are lands that contain facilities for park managers and visitors. Special-use zones include lands and waters where activities can occur that are not appropriate for other zones (e.g., mining and cattle grazing) (153).

The National Wilderness Preservation System (NWPS)-This system is somewhat different from the National Park System and the National Wildlife Refuge System because no single agency administers it The 92 million-acre NWPS is a collection of areas under special management from each of the four major land-management agencies (the U.S. Department of Agriculture's Forest Service and DOI'S Bureau of Land Management (BLM), NPS, and FWS). The Wilderness Act of 1964 (P.L. 68-577), which established the NWPS, mandates stricter protection of resources in their natural state than any other Federal land designation. Its mandate is "to secure for the American people of present and future generations the benefits of an enduring resource of wilderness . . . in such a manner as will leave them unimpaired for future use and enjoyment and so as to provide for the protection of these areas, the preservation of their wilderness character." Any road building, construction, or use of motorized equipment is generally prohibited by the act, but some mining, grazing, and prospecting may be allowed in certain areas. Although "each agency administering any areas designated as wilderness shall be responsible for preserving the wilderness character," management of individual Wilderness Areas is the responsibility of the land-management agency that managed the lands before they were designated, and interpretation of that mandate may not be uniform across the system.

The National Wild and Scenic River System (NWSRS)-Like the NWPS, the NWSRS is largely a special management designation for rivers under various Federal ownerships. The Wild and Scenic Rivers Act of 1966 (WSRA) (P.L. 90-542) established the Wild and Scenic Rivers System, now covering 9,260 miles (15,000 kilometers)[4] 0n 119rivers, so that rivers possessing "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations." Management may vary among rivers in the system.

Other Federally Protected Natural Areas--Several other Federal designations are aimed at preserving land and wildlife in their natural state. The loosely coordinated Federal system of Research *Natural Areas* (RNAs), originally established for research and education purposes, are areas where natural ecological processes are allowed to govern. The system currently includes over 400 units covering more than 4 million acres. Like Wilderness Areas, RNAs are special management designations in various Federal Iand-rnanagement systems such as the National Forest System or the National Park System. BLM is directed to identify Areas of Critical Environmental Concern (ACECS) in its land-use planning. These are areas "where special management attention is required . . . to protect . . . important . . . historic, cultural, or scenic values, fish and wildlife resources or other natural processes" (P.L. 94-579). This designation accounts for over 6 million acres of BLM land (some RNAs are also ACECS). The system of ***National Natural Landmarks,*** administered by NPS to "identify and encourage the preservation of the full range of ecological and geological features that are nationally significant examples of the Nation's natural heritage" is useful for identifying important natural areas-especially those on private land. However, this designation relies on the stewardship of the landowner to voluntarily protect the land(7). The U.S. Man and the Biosphere Program (USMAB) is part of an international program administered by the United Nations Educational, Scientific, and Cultural Organization (Unesco) designed to foster cooperative protection of the biosphere, This objective is realized through the establishment of an international network of ***Biosphere Reserve*** areas with rnultiple ownership that represent the wide range of the Earth's ecosystems. Although designation of an area as a Biosphere Reserve is purely honorary, cooperative management, research, and education are strongly encouraged on the reserves and are seen as integral components of fulfilling USMAB'S mission. Many National Parks in the United States are also core areas of these Biosphere Reserves.

Other Natural Areas-Although preservation of wildlife and Biodiverslty has not been the top priority in managing National Forests or Federal public lands, many National Forests and public lands are not frequently

4 To convert from miles to kilometers, multiply by 1.607.

(Continued on next page)

Box 5-C-Federally Protected Natural Areas: The Legislative Framework-(Continued)

harvested, mined, or grazed and play a critical role in providing habitat and continuous landscapes for wildlifeand fish species. National Forests and public lands near natural areas can also be important for providing supplemental habitat, for buffering natural areas from certain threats, and for minimizing fragmentation and development. Because they fill the same role as some natural areas in protecting species and ecosystems, they are de facto natural areas.

Likewise, all States have some system of protected lands: State parks, State forests, or State preserves. The contribution of these lands to preservation efforts is significant. In addition to receiving matching-grant funds from the Land and Water Conservation Fund (LWCF) and other Federal programs, most States have passed laws designed to promote natural area conservation on private lands (62).[5] One important State effort that helps guide and focus State conservation efforts is The Nature Conservancy's National Natural Heritage Program. This voluntary program is operated in cooperation with various State agencies to collect, manage, and use biological, ecological, and related information.[6] This information is then used to prioritize State and Nature Conservancy conservation efforts. Heritage programs have been established in all 50 States.

5 Although LWCF funds provided to the States are often used to develop recreational sites and facilities, many of these projects also protect open space and natural vegetation and may have significant benefits for wildlife (6).

6 Typically, The Nature Conservancy provides methods, training, and technical support and coordinates data exchange and interstate collaboration while State agency personnel actually conduct the inventories (86).

SOURCE: Office of Technology Assessment, 1993.

Table 5-2—Management Goals for Some Federally Protected Natural Areas

System title, managing agency	Acres in millions[a] (in Alaska only)	Goals	Degree of protection from human intervention
Wilderness Preservation System, multiple agency	94 (57)	To preserve "wilderness character . . . unimpaired for future generations" (P.L. 88-577).	High
National Park System, National Park Service	73 (53)	To conserve the scenery, natural and historic objects, and wildlife so that they will be left unimpaired for future generations (16 U.S. Code 1).	High
Biosphere Reserves, multiple agency	32 (17)	To solve problems associated with the effects of human impacts, over time, on natural ecosystems through a categorization that includes a core protected area, buffer zones, and transition areas (73).	Depends on zone
Wild and Scenic Rivers, multiple agency	10,500[b] (3,210)[b]	To preserve rivers (and their immediate environments) with outstanding scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values in their free-flowing condition for the benefit and enjoyment of present and future generations (P.L. 90-542).	High-medium

System title, managing agency	Acres In millions[a] (In Alaska only)	Goals	Degree of protection from human Intervention
National Wildlife Refuges, Fish and Wildlife Service	(76)	"TO preserve, restore, and enhance threatened and endangered species In their habitats; to perpetuate the migratory bird resource; to preserve a natural diversity and abundance of flora and fauna; to provide education and recreation to the extend that these activities are compatible with refuge purposes" (148).	Medium
Marine Sanctuaries, National Oceanic and Atmospheric Administration (NOAA)	0.02	"To protect marine and Great Lakes areas with conservation, educational, aesthetic, recreational, historic, and/or educational value of national significance" (OOCRM)[c].	High-medium
Research Natural Areas, multiple agency	5	"To provide for studies of naturally functioning ecosystems that can serve as ecological reference points for baseline monitoring and oontrols for experimental research" (57).	Medium
Natural Estuarine Research Reserves, National Ocean and Atmospheric Administration and State agencies	0.4	"TO protect representative examples of the United States' diverse estuarine biogeography and typology" (OOCRM)[c].	Medium-low
National Forest System, Forest Service	191 (22)	"The National Forests are established and shall be administered for outdoor recreation, range, timber, watershed and wildlife and fish purposes" (P.L 86-517).	Medium-fow
Public lands, Bureau of Land Management	269 (90)	To "protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resources, and archaeological values" based on the principles of multiple-use and sustained yield (P.L. 94-579(a)).	Medium-low
Other (includes Experimental Ecological Reserves, Experimental Forests, Ranges and Watersheds, Outstanding Natural Areas Management, Areas of Critical Environmental Concern, National Rivers, and National Environmental Research Parks), rnultiple agency	5	Varies	Varies

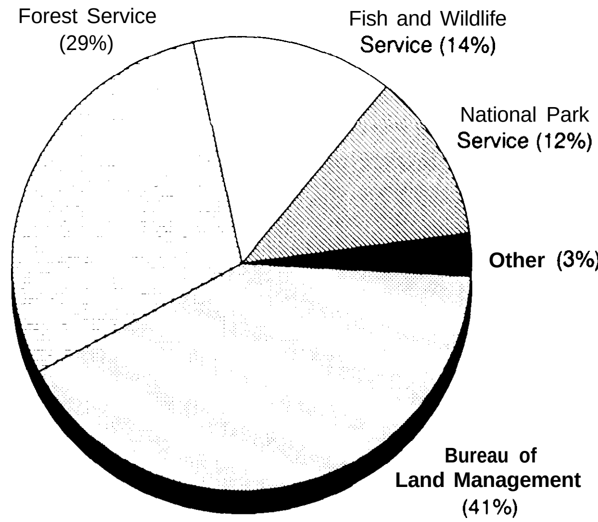
a Except for Wild and Scenic Rivers. To convert acres to hectares, multiply by 0.405.
b In miles (I 7,000 and 5,200 kilometers, respectively).
c Office of Ocean and Coastal Resources Management, NOAA, personal communication, Sept. 8, 1993.

SOURCES: Man and Biosphere Program, *Practical Guide to MAB* (Park, France: Unesco, Division of Ecological Sciences, June 1987); U.S. Congress, Congressional Research service (CRS), *The Major Federal Land Management Agencies of Our Nation's Land and Resources*, prepared by A. Bachlel, Environmental and Natural Resources Policy Division (Washington, DC: CRS, Feb. 8, 1993); U.S. Congress, Office of Technology Assessment, *Technologies to Maintain Biological Diversity*, OTA-F-30 (Washington, DC: US. Government Printing office, March 1987); U.S. Department of the Interior, Fish and Wildlife Service, *Application Manual for the Land Acquisition Priority System*, Version 5.0, July 1992.

Why Are Natural Areas Valued?

Natural areas are valued for the distinctive character offered by a mix of physical and biological factors. Many of the most notable federally protected natural areas are famous for their spectacular scenery (e.g., gorges and canyons), vegetation (e.g., alpine wildflowers, fall foliage, and giant sequoias), and abundance of unusual wildlife (e.g., grizzly bears, alligators, and certain birds). The particular composition of the landscape, vegetation, and animal species makes natural areas valuable for certain kinds of outdoor recreation such as camping, hiking, sightseeing, wildlife watching, fishing, and, in some places, hunting and trapping. The rare species and biological diversity that natural areas harbor and protect also contribute to the areas' recreational value and unique character.

Figure 5-4A-Federally Owned Lands: Agency Jurisdiction



Over 75 percent of land-based outdoor recreation occurs on Federal land, and recreational use of Federal natural areas is increasing (131). In 1992, people made over 274 million visits to units of the National Park System—representing an increase of over 76 million annual visits since 198@ (see fig. 5-5). According to a 1991 survey of fishing-, hunting-, and wildlife-associated recreation, over 108 million U.S. residents participated in viewing, photographing, and studying wildlife that year (152). Wildlife-associated recreation can also contribute significant.ly to local economies. Over $18 billion was spent on activities and equipment related to viewing, photographing, or studying wildlife in 1991 (152).

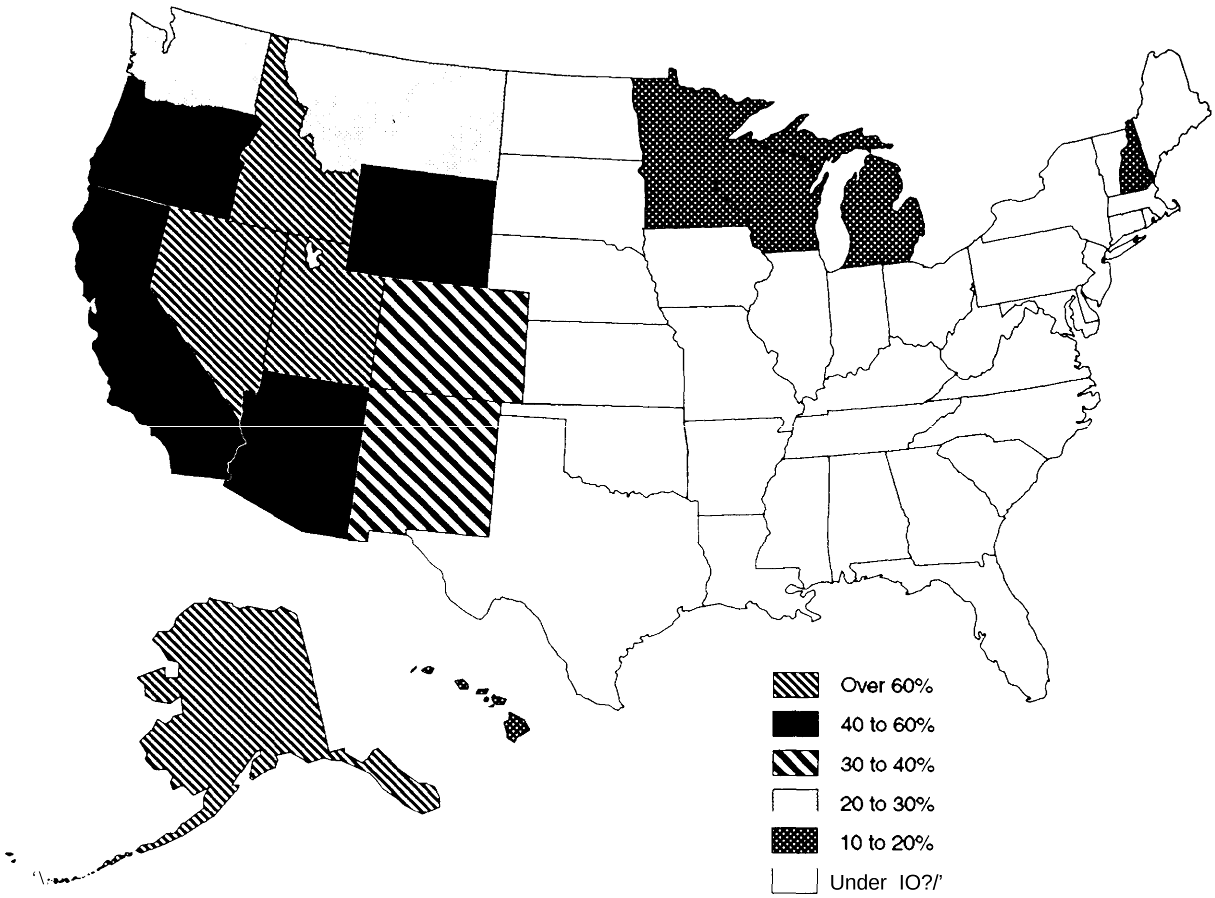
Demand for recreation that requires remote areas, such as hiking, camping, and wildlife watching, is expected to increase faster than any other outdoor recreation (13 1). However, because of development pressure, opportunities for this kind of recreation are projected to decrease in the future (131). Because of these trends, Federal natural areas may eventually become even more valued for remote outdoor recreation.

Federally protected natural areas are playing a larger role in conserving rare species and biological diversity than they have in the past (13, 35,66, 100). In 1993, the list of species considered endangered or threatened in the United States surpassed 800,[9] with thousands of additional species officially awaiting consideration for threatened or endangered status (146). Because destruction of habitat remains the main cause of species extinctions, preservation of adequate natural habitat is a key factor for most recovery efforts (126, 146, 176). As a result, many federally protected natural areas with suitable habitat for endangered species are an increasingly important component of endangered species recovery programs. If climate change accelerates the rate at which species are threatened with extinction, Federal natural areas may become even more valuable for species-protection efforts. Box 5-D illustrates the

[8] K. Hornback, U.S. Department of' the Interior, National Park Service, personal communication, August 1993.

[9] U.S. Fish and Wildlife Service, Endangered Species Office, personal communication, August 1993.

Figure 5-4 B-Federally Owned Lands: Percentage of State Area



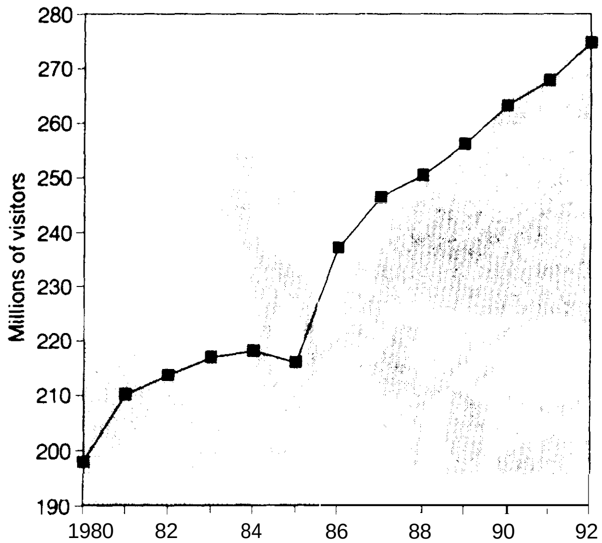
SOURCES: Congressional Research Service, 1993; U.S. Geological Survey, 1993.

kinds of problems climate change could pose for species protected under the Endangered Species Act (P.L. 93-205).

The loss of species, communities, and ecosystem types means a loss of biodiversity. Society benefits in many ways from biodiversity—medically, socially, culturally, and spiritually (see table 5-3)-but one of the most compelling reasons for conserving it may lie in the fact that species are irreplaceable. Maintaining biological diversity *may be* especially important if the natural world is to be able to adapt to environmental stresses such as changing climate (13, 96, 98).

Although the debate continues over how best to conserve biodiversity, management policies of some Federal natural areas increasingly recognize the importance of conserving ecosystem and species diversity. For example, the National Park Service's policy is to conserve the diversity of native plant and animal species in units of the National Parks System. Conservation of biodiversity is an explicit consideration for future additions to the National Park System (153). Federal natural areas may become the focal point for the protection of biological diversity, as they are now for the protection of endangered species

Figure 5-5-Recreational Visits to National Parks



NOTE: Numbers cited for recreational visits do not include travel to and from private homes, through traffic, or visits for business purposes.
SOURCE: National Park service, 1993.

M. CUTLER

River narrows, such as this one in Utah's Zion National Park, lure countless hikers each year. Public use of the Nation's parks and wilderness areas is becoming increasingly popular and is expected to continue to rise in the future.

-especially if trends in existing stresses continue.

Federal natural areas systems are defined by legislative requirements that provide the basis for their management. These legislative requirements and management directives are what make each system slightly different. Table 5-2 summarizes the management goals for various types of Federal natural areas.

The Organic Act of 1916 (16 U.S. Code (U.S.C.) Sec. 14,22,43) established the Park Service to administer the National Park System "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such management and such means that will leave them unimpaired for future generations." In addition, each National Park unit possesses its own goals and management philosophy. Over 20 different designations are used to classify management of some 340 units of the National Park System. Each designation reflects the values for which the area was protected. Some National Park System units, such as National Battlefields or National Memorials, are protected for political or historical purposes. National Park System units valued primarily for their natural qualities include National Parks, National Monuments, National Preserves, National Seashores, National Lakeshores, and National Rivers. Because nearly half of the National Park System acreage is held as National

Box 5-O-Implications for Endangered Species Conservation Under a Changing Climate

Climate change is likely to alter the environment and habitat for all organisms. Many rare or endangered spades require specialized environmental conditions and are extremely sensitive to changes in their habitat. In many cases, these species are already threatened by habitat loss. Climate change could accelerate their decline and push them to the brink of extinction (see box 2-E for details on how species may respond to climate change). The United States has one major mechanism for protecting species in danger of extinction: the Endangered Species Act (ESA) of 1973 (P.L. 93-205). Despite this law, species are still declining at increasing rates, the backlog of species awaiting protection under ESA is growing, and conflicts between protection of species habitat and human development are intensifying. The 1982 amendments to ESA provide an avenue that may help resolve the potentially bitter conflicts between species protection and economic development: habitat conservation plans (HCPS). These are voluntary agreements among the Federal Government, developers, and other stakeholders that provide species protection while allowing some small amount of habitat destruction. Although HCPS are not a substitute for species protection, they do offer a creative solution to some conflicts and backlog problems.

Natural areas, rare species, and climate change-Most species depend on suitable natural habitat for survival. The rapid conversion of natural habitat to agriculture and settlements over the past century has led to the decline of a diverse array of species that depend on them. Because there is little opportunity to regulate the use of private lands, protected natural areas on public lands have become the focus of habitat protection for declining species. Nearly 200 species of threatened and endangered amphibians, birds, clams, crustaceans, fish; insects, mammals, reptiles, snails, and plants live on National Wildlife Refuges. Many refuges contain several endangered species, and over 30 National Wildlife Refuges have been established specifically to protect endangered species. Also, lands of the National Park System provide protection for one-third to one-half of the rare and endangered species in the United States (1 77). Wilderness Areas on Bureau of Land Management and Forest Service lands also contain numerous rare species.

Climate change could accelerate the rate of species decline, thereby adding substantially to the list of species threatened with extinction. Habitats for rare or declining species are often already isolated or fragmented and are extremely sensitive to any environment! changes (see box 5-E). Many endangered species require specialized environmental conditions. Climate change is likely to substantially change the conditions of many habitats within and outside natural areas and perhaps make them unsuitable to sustain certain species (see ch. 2). Some species may not be able to adapt.

The implications for natural areas are numerous. Natural areas may become like large-scale zoos, requiring intensive management to protect species from extinction. Widespread species decline coupled with continued habitat destruction and modification could make natural areas more valued for species protection. Because natural areas may offer the only option for survival other than captivit y in zoos or botanical gardens, public pressures may build to use increasingly intensive management to sustain species mixes and concentrations that might no longer otherwise be self-sustaining. On the other hand, the impacts of climate change on natural areas may make them less able to provide choice habitat for species, and thus less able to protect species from decline or extinction. If species are no longer adequately protected in natural areas, fulfilling the mandate of ESA may increasingly require the cooperation of private landowners.

The Endangered Species Act—The Endangered Species Act of 1973 was enacted to stem loss of species. It represents a commitment to preventing extinction even if that means tempering economic gain and development (8, 50). Under the act, which is administered primarily by the Fish and Wildlife Service (FWS),[1] a scientific assessment determines whether a species is threatened with extinction by habitat destruction or overuse, disease,

1 Future administration of the Endangered Species Act, or parts of it, may become the responsibility of the new National Biological Survey in the Department of the Interior.

(Continued next page)

Box !W-implications for Endangered Species Conservation Under a Changing Climate--Continued)

or other factors. If such a determination is made, the species is “listed” and awarded Federal protection. To protect a listed species, the act directs all Federal agencies to “use all methods and procedures necessary” to help the listed species recover. Specifically, all Federal agencies (through consultation with the Fish and WildlifeService) are to ensure that their actions do not jeopardize the existence of the species.

Since its enactment, several important lessons and issues have emerged that were not foreseen in the act’s early years. First it is now clear that the threat of extinction is much more far-reaching in the United States than was recognized 20 years ago(8). Over 800 species are currentl`y listed as endangered, and thousands more are *candidate* species, awaiting consideration for listing. Second, programs focused on recovery and protection efforts require far more resources than have been made available (8). The Fish and Wildlife Service's Endangered Species Program has grown from about $4.5 million in 1974 to over $30 million in 1988, and still the status (improving or declining) of about 20 percent of listed species is unknown, and backlogs for listing candidate species continue to grow (103, 145). By the time the winged maple leaf mussel was listed as endangered in 1990, 99 percent of its habitat had been lost and only one population remained (71). Similarly, the polo de jasmine plant was listed in 1991 with only one individual remaining (71). Many candidate species maybe completely extinct before they are listed (103). Habitat destruction caused by human development is the main cause of continuing species decline, and conflicts over development and destruction of habitat are becoming more frequent and more intense.

There is a growing consensus that those administering the Endangered Species Act are overburdened. Yet it is likely that climate change will accelerate species decline. Adding more species to the list may dilute efforts to protect other listed species so that none are protected adequately. On the other hand, earlier listing may help recovery prospects. By the time species are listed, their habitats are usually destroyed or badly degraded, their populations are dangerously low, and their genetic diversity is seriously reduced (19, 175). To date, less than 10 percent of all listed species are considered to be improving (145), 2 percent (1 1 species) are extinct, and despite some herculean efforts, species loss continues. Only 15 species in the history of the act have recovered (103). Protection for imperiled species may simply come too late. In 1992, the Fish and Wildlife service announced measures to expedite the listing process, which are expected to help improve the chances for survival for many species currently awaiting listing (106).

One partial solution to this problem maybe to begin protecting species before they become endangered-by preserving habitats at a broad, ecosystem level (109). This “preventive care” approach may help augment the “emergency room” efforts under the Endangered Species Act. Conservationists have long called for a broadbased, multispecies protection effort and the current administration is beginning to embrace this concept for Federal conservation efforts (5).

Habitat conservation plans: Hope for species under climate change?—The Endangered Species Act requires the designation of critical habitat (areas that are “essential to the conservation of the species”) when a species is listed, as well as development of a recovery plan, detailing actions to aid species recovery. Recovery plans for listed species must identify specific recovery actions (which mayor may not include protection and management of critical habitat), estimate a time frame and costs for recovery, and establish criteria by which to measure recovery status. Economic impacts can be considered in both the designation of critical habitat and the development of a recovery plan. However, because of the lack of personnel, resources, and adequate scientific information, many species do not have designated critical habitat and over 40 percent of Iisted species do not have a recovery plan.

Because Federal agencies are explicitly directed under ESA to conserve endangered species and are forbidden to jeopardize the existence of endangered species, conservation rnechanisms such as the designation of critical habitat and development of recovery plans have focused on regulating Federal activities. However, the increasing decline of species and continued habitat destruction have required more aggressive extension of ESA provisions to private landowners and local governments. Conflicts have increased in the past decade over the application of Section 9, which prohibits any "taking" of spa-es, to private property. The 1982 amendments to ESA established a mechanism to address this issue.

The 1982 ESA amendments allow the fish and Wildlife Service to issue incidental "take" permits (e.g., permits to destroy a certain amount of species) in cases where developers and landowners have an approved HCP that would provide for long-term protection for the species elsewhere.[2] This approach explicitly makes a compromise between economic development and endangered species protection. Typically, an HCP establishes a Federal natural area and employs other land-management techniques such as zoning, habitat restoration, and management agreements to provide habitat protection (1 O). This approach to species conservation may become a favored mechanism in the future because it approaches long-term conservation at a larger, ecosystem level, it could provide an alternative to large direct acquisitions, and it provides a forum for bringing together many landowners and interest groups. However, it is too early to tell whether the HCPS that have been prepared will provide the long-term protection of the species t hey are designed to protect.

One notable example is the Coachella Valley Fringe-Toed Lizard. HCP, designed to protect an endangered lizard that is uniquely adapted to its sandy desert habitat in California. Fringed toes, wedged snout, double-sealed eyelids, and ear flaps are all features unique to this species and serve some function for its survival in the desert. In 1983, conflicts overdevelopment of 400 acres (162 hectares)[3] of the lizard's habitat resulted in an agreement among conservation groups, developers, local governments, State governments, and Federal agencies to develop an HCP for the area (1 O). Biological assessments are required under ESA to help design the protection plan that would maximize chances for long-term survival. The final plan included the establishment of three habitat reserves, each with its own sand source, and an agreement t hat adjacent Bureau of Land Management (BLM) lands were to be managed to protect about 15 percent of the lizard's potential habitat (about 370,000 acres) (1 O). Acquisition funds were provided by the Federal Land and Water Conservation Fund, a BLM land exchange, The Nature Conservancy, and mitigation fees paid by developers.

Although HCPS are an attractive model for resolving conflicts over endangered species preservation on private lands, they are not without problems. It is not clear that HCPS themselves ensure long-term habitat protection. Some criticize that an HCP essentially amounts to a license to destroy critical habitat in exchange for establishing a "zoo" requiring intensive management (10). If HCPS allow development just outside the preserved habitat, the effects of fragmentation and habitat isolation could degrade the protected habitat (e.g., development could leave only the 15 percent of protected fringe-toed lizard habitat intact). In addition, most conflict that results in the development of HCPS are near urban areas. Close proximity to urban development may indirectly degrade habitat despite protection under the plan. On the other hand, HCPS may be the only alternative for habitat protection in densely populated areas.

To effectively protect the national interest in these plans and perhaps to address some of these concerns, FWS personnel who are involved in these negotiations and responsible for implementing the act should have the skills necessary for negotiating with developers, economists, and politicians. Many negotiators from FWS are

2 The development of habitat conservation plans is different from the designation of critical habitat or the development of recovery plans. HCPs are voluntary agreements pursuant to the "taking" prohibition of Section 9, whereas designation of critical habitat and development of recovery plans are mandated. However, the development of an HCP mayor may not Include the formal protection of a designated critical habitat, and some recovery plans may overtap with portions of the HCP. Nevertheless, because an HCP is a localized plan, It is not a substitute for the development of an overall recovery plan for a species or for the designation of Its critical habitat.

3 To convert acres to hectares, multiply by 0.405.

(Continued on next page)

Box 5-D-implications for Endangered Species Conservation Under a Changing Climate-(Continued)

wildlife biologists with expertise infield biology and perhaps few skills in negotiation involving multiple interests and disciplines.[4] In addition, the scientific knowledge required to maximize species survival under a localized plan is often not available (scientific information is also lacking for the mandated recovery plans and for designation of critical habitat), and HCP preparation and implementation are not cheap (1 O). Because most sensitive habitat is near urban areas, market values are high and acquisitions are expensive. Moreover, most funding for HCPS to date has come from Federal sources.

HCPS also do not consider the larger issues of biodiversity because they are targeted to a single species under the Endangered Species Act. A multispecies approach to conservation is frequently cited as the most effective, but a few plans, such as the Balcones Canyonlands HCP, are beginning to take a broader approach (10). The Balcones Canyonlands HCP seeks to provide protection for three endangered species as well as several rare plants and invertebrates by preserving large habitat areas pursuant to an overall biological assessment of habitat requirements for several species. Even so, HCPS are only pursued when a species is on the brink of extinction. There is no mechanism for instituting conservation efforts when populations are still healthy. As conflicts between human development and species survival become more frequent and intense, and as more and more species are threatened with extinction from climate change and other stresses, new approaches to conservation will be needed. HCPS, if properly developed and implemented, could be expanded from focusing on endangered and threatened species to addressing a broader set of conservation efforts, including conservation of biodiversity (120).

[4] M. Bean, Environmental Defense Fund, personal communication, May 1993.

SOURCE: Office of Technology Assessment, 1993.

Parks, and the other types, such as National Monuments, make up a relatively small proportion of the units valued for natural qualities, this chapter focuses primarily on National Parks.[10]

The "crown jewels" of the National Park System (the oldest and largest National Parks such as Yellowstone, Yosemite, Grand Canyon, and Glacier) were originally preserved for recreation opportunities, outstanding scenery, and unique geologic features (177). Current management policies reflect an expansion of National Park Service emphasis to include the preservation of ecosystems and biological diversity. Today, areas are designated as new National Parks only if they contain rare remnant or disappearing landscapes or biotic types, exceptional biological diversity or geological features, rare or unique species or communities, or outstanding scenic qualities (153).[11]

Most National Wildlife Refuges were established to protect and manage populations of a single species or species group such as migratory waterfowl (6, 125). The Fish and Wildlife Service is beginning to take a broader approach to managing the refuges. More and more refuges are using the "ecosystem management" approach, and a biodiversity target has been developed for new acquisitions. Its current mission is to "provide, preserve, restore, and manage a national network of lands and waters sufficient in size, diversity, and location to meet society's needs for areas where the widest possible spectrum of

10 However, because many of the other designated units (e.g., National Preserves) are designed to protect natural qualities and because the management of these areas is similar to that of National Parks, much of this chapter applies to these units as well.

11 The National Park Service uses these criteria to rank proposed additions to the National Park System, but Congress ultimately designates through legislation which land will be acquired for use as National Parks.

Table 5-3-Examples of Benefits from Ecosystem, Species, and Genetic Diversity

Ecological processes	Research	Cultural heritage	Recreation and tourism	Agriculture and harvested resources
Ecosystem diversity Maintenance of productivity; buffering environmental changes, protection of watershed and coastal protection.	Natural research areas; sites for baseline monitoring.	Sacred mountains and groves; historic landmarks and landscapes (e g , Voyageurs Park, MN)	275 million visitors per year to U.S. National Parks	Rangelands for livestock production (e.g., 34 in the U.S.); habitats for wild pollinators and pest enemies (e.g , saving $40 to $60 per acre, or per 0.4 hectare, for grape growers).
Species diversity Protection of the role of plants and animals in forest regeneration, grassland production, and marine nutrient cycling	Models for research on human diseases and drug synthesis (e.g., bristlecone pine, desert pupfish, medicinal leeches)	National symbols (bald eagles); totems; objects of civic pride (e.g., bowhead whale, *Ficus religiosa),*	In **1991, 76 million people in the United States observed, photographed, and/or fed wildlife; 36 million fished; 14 million hunted**	Commercial logging, fishing, and other harvesting industries ($27 billion/year in United States); new crops (e.g., kiwi fruit, red deer, catfish, and Ioblolly pine).
Genetic diversity **Protection of the raw materials of evolution required for survival and adaptation of species and populations,**	Fruit flies in genetics, corn in inheritance, and Nicotiana in virus studies	**Bread and cultivars of ceremonial, historic, aesthetic, or culinary value (e.g , Texas longhorn cattle),**		Required to avoid negative selection and for enhancement programs; pest and disease resistance alleles.

SOURCE: U S. Congress, Office of Technology Assessment, *Technologies to* **Maintain** *Biological Diversity,* **OTA-F-30 (Washington, DC: U.S. Government Printing Office, March 1987); 1987; U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, Bureau of the Census, 1991 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, (Washington, DC: U.S. Government Printing Office, 1993).**

benefits associated with wildlife and wildlands is enhanced and made available" (147). Waterfowl hunting and other "compatible" recreation uses are also valued services provided by this system.

Wilderness Areas are protected and preserved for their "wilderness character," where "earth and community of life are untrammeled by man, where man himself is a visitor who does not remain, . . . which generally appears to have been affected primarily by forces of nature,. . . [which] has outstanding opportunities for solitude or a primitive and unconfined type of recreation; . . . [and also contains] ecological, geological, and other features of scientific, educational, scenic or historical value" (P.L. 88-577). Simply, Wilderness Areas are valued because they have remained relatively untouched by human activity .12

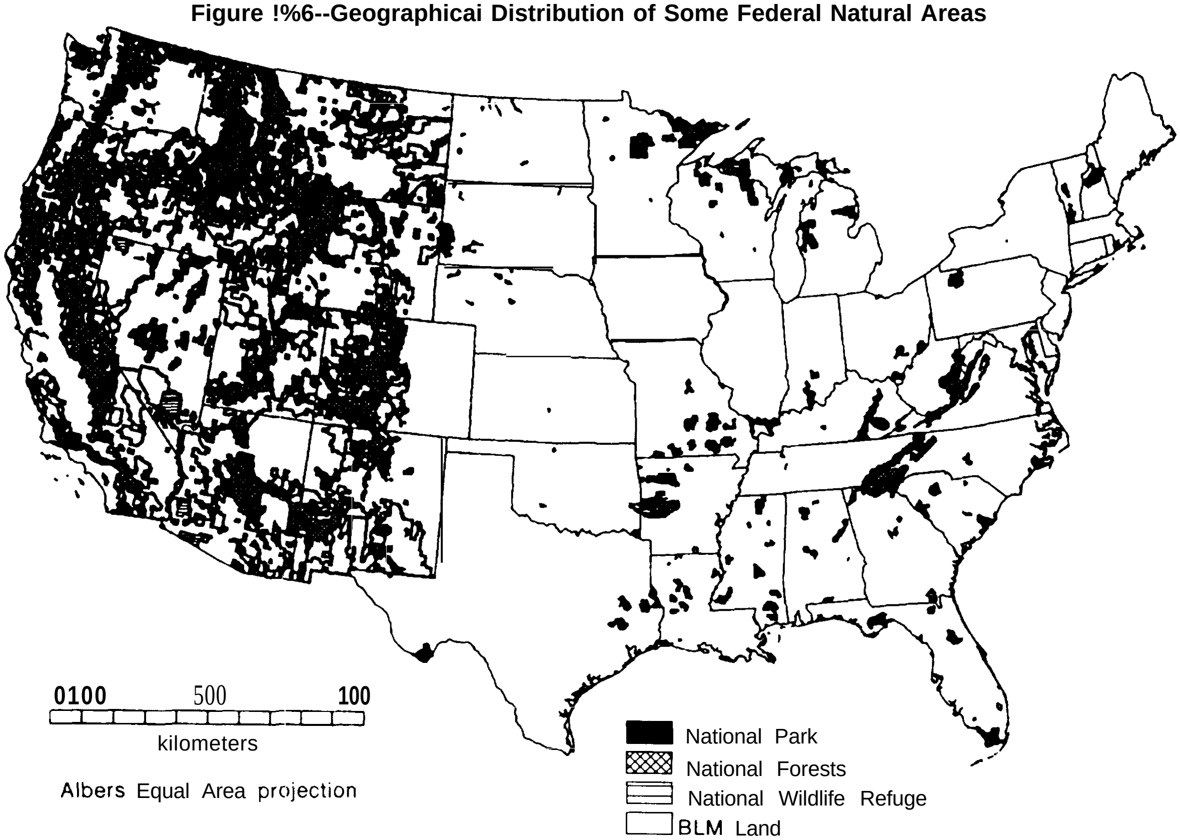
Existing Stresses on Protected Natural Areas

Landscape Fragmentatlon

The complete list of existing threats to natural areas includes nearly every type of human activity within and near designated natural areas, ranging from poaching to visitor use to air pollution to industrial development (52, 154, 159), but perhaps the most pervasive threat to all natural areas is the *landscape fragmentation* that results from development and the encroachment of human

12 In the eastern United States, some areas have been designated as Wilderness even though they were once heavily farmed because they have grown wild and seem pristine to an untrained eye. This practice is most common where more-pristine areas do not exist.

Figure !%6--Geographicai Distribution of Some Federal Natural Areas



NOTE: Protected lands in the heavily populated East are already quite fragmented. Much more land Is protected In the West, but as this map shows, adjacent parcels are often managed by different agencies with different goals.

SOURCE: J. Jones, U.S. Geological Survey, 1993,

activity. These activities effectively dissect the landscape into smaller and smaller parcels. Natural areas become ''islands' of habitat surrounded by developed or altered landscapes and are vulnerable to a variety of stresses. Figure 5-6 shows the distribution of National Parks, National Forests, National Wildlife Refuges, and BLM lands in the continental IJnited States. Although most larger and older natural areas are protected, or "buffered," by adjacent undeveloped areas managed for multiple uses (e.g., National Forests) that effectively increase their size, many Federal natural areas are not large enough to withstand future stresses or to sustain ecosystems on their own (29, 51, 75). Geographic fragmentation is also a problem within natural areas as demands for roads and facilities to support recreational use increase. As natural areas become more fragmented, they become more vulnerable to stresses, including climate change, especially if the area is not large enough to absorb the impacts of numerous threats. Box 5-E describes the numerous threats to natural areas caused by landscape fragmentation.

Institutional Fragmentation

Institutional fragmentation also affects natural areas. The two Cabinet-level departments that manage the most land are the Department of the Interior and the Department of Agriculture. Under these departments are four major land-management agencies: the Forest Service in the Department of Agriculture and the Bureau of

Box 5-E-Landscape Fragmentation: Islands of Nature in a Sea of Human Activity

Since civilization began, humans have been shaping the landscape with tools ranging from hand-held axes and hoes to chainsaws and bulldozers. Throughout much of history, these activities carved out relatively small patches of land for uses including agriculture, timber harvesting, mining, and dwelling. The intensively used patches were still surrounded by vast natural areas where ecosystems continued to function more or less undisturbed. As the human population has grown and encroachments into the landscape have expanded, human actions have affected ever larger areas and have carved the landscape into ever smaller patches. In many areas, the landscape is now characterized by a predominance of land used for human activities surrounding small remnant patches of the original ecosystems-islands of nature in a sea of human activit y. Barriers such as roads, buildings, and vast stretches of cleared and chemically treated agricultural fields may separate the plants and animals that inhabit the remnants of formerly extensive ecosystems. These remnant wildlands contain much of the diversity of terrestrial species that remains in this country, and afford the last invaluable glimpses of the structure and function of ecosystems as they were once composed. Many remnant wildlands are already too small to sustain habitat for some species without active management (1 9).

Although fragmentation of the landscape is not necessarily bad, it becomes a problem when species cannot easily migrate from one area to another and when a habitat area is too small or poor in quality to sustain viable species populations. The effects are often not immediately obvious nor are they always noticeable in each location, but they accumulate over time and space. Fragmentation poses several distinct types of problems for plants and animals and the larger communities in which they interact.

Small size-Fragmented landscapes may simply be too small to supply the forage and habitat needed by individuals of various wide-ranging species. For example, the Florida panther routinely roams over a territory of 200 square miles (520 hectares)[1]. The highly developed Southern Florida landscape offers an obstacle course of roads and fields that limit the panther's possibilities for finding prey and leave the panther vulnerable to dangers such as cars. The endangered red cockaded woodpecker prefers to stay in wooded areas. When it must travel through open fields to find new forest dwellings, it is at a much higher risk of predation from owls and hawks. Pairs of northern spotted owls require a territory of several thousand acres to support food gathering, nesting, and reproduction. The owls scout out territory in more or less random directions from their former sites; if t hey do not find suitable nesting sites within several weeks, they may fail to reproduce or, in extreme cases, even die from hunger and exhaustion (16). Numerous other species such as bears, wolves, moose, and elk range over large territories but have rather specialized requirements for food and habitat (see fig. 5-3). If climate change alters vegetation patterns, such species may have to travel even farther to satisfy their nutritional requirements. For some species, an open space such as a field or road imposes an enormous behavioral barrier that will be crossed only with great reluctance. Such species may effectively become trapped in a small area even if other suitable habitats are relatively close by. When suitable habitat has been diminished to small and distantly separated parcels, populations of many of these species decline. Isolation can also interfere with effective pollination and seed dispersal.

Local extinctions-Another consequence of fragmentation is that the populations of plants and animals that remain on a patch may have less genetic variability than does the species as a whole. Limited variability offers fewer possibilities for adaptation to changes in the environment (see ch. 2). Small, isolated populations maybe more vunerable to extreme events, such as fires, storms, drought, and late spring or early fall frosts-many of which could become more common as the climate changes, and any of which could lead to local extinction. When enough local populations become extinct, the species as a whole is endangered.

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1 To convert square miles to hectares, multiply by 2.590.

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Box 5-E—Landscape Fragmentation: Islands of Nature in a Sea of Human Activity-(Continued)

More edges-Fragmentation also creates many more edge areas compared with the amount of land in the interior of a habitat zone. As the landscape is divided up into more and smaller patches, the area that lies at the edge of a patch increases. Forest edges are often zones of high diversity because the varied light conditions offer a range of habitats and because they are areas where species from surrounding ecosystems may mix with forest species However, many of the species that inhabit the edges are invasive species that can displace forest flora and fauna For example, the cowbird, which rarely travels deeper into a forest than several hundred feet from a clearing, is an aggressive competitor with many songbirds. What many ecologists fear is that increasing the amount of edge may lead to a predominance of invasive and opportunistic species at the expense of an array of historic species. The drying effects of the wind are generally greater at the edges of forests and wetlands than in the interior, so as the ratio of edge to interior increases, so does the area susceptible to drought. In some areas, cutting back forests has been linked to changes in wind and precipitation patterns, and in extreme cases, it may lead to desertification.

Loss of transition zones-Fragmentation may obliterate the transition zones between different types of vegetation or leave them separated by a large distance. This poses a problem for species that rely on different types of habitat during different stages of their life cycles or during some seasons. For example, some species of butterflies spend their larval stages on cordgrass, which grows in coastal wetlands, but live their adult lives in habitats farther upland and inland. Land-use patterns that diminish or destroy the gradual transition between wetlands and upland areas disrupt the butterflies' reproductive cycles. The clapper rail, an endangered bird in Southern California, is a another example. Although dapper rails dwell within the tidal zone of coastal wetlands, they prefer to remain just above the reach of the water, past the high-tide line. However, in many areas (even those bordering protected natural areas), development has occurred right up to the high-tide line. To escape January and June high tides and numerous storm surges throughout the year, clapper rails often end up perched on cars in seaside parking lots or near the edges of roads, where t hey are vulnerable not only to cars but also to predation by domestic cats and dogs. Sea level rise due to climate change could further squeeze, if not eliminate, the transition zone between coastal wetlands and uplands.

Natural areas in the United States today often make up relatively small patches in a larger fragmented landscape. Although most large and older natural areas are buffered, or protected, by adjacent natural areas or by de facto natural areas (such as multiple-use lands managed by the Forest Service or Bureau of Land Management) that effectively increase their size, many ecologists claim that most Federal natural areas are not Iarge enough to sustain ecosystems without suffering from some impacts of fragmentation (29). Combating those impacts is not easy. In general, the !arger the contiguous area of land maintained with minimal human disturbance, the less severe will be the consequences of fragmentation. However, even if the public wanted to set aside vast new natural areas to protect a range of ecosystems, large relatively undisturbed sites simply do not exist anymore in the East, and opportunities are quickly disappearing in the West. Many actions that humans may make in response to climate change could accelerate the process and damage of fragmentation; the movement of agriculture into new areas and increased water diversions could aggravate existing problems (see vol. 1, chs. 5 and 6).

Buffer zones around natural areas and corridors connecting different natural areas can help guard against some fragmentation effects and allow for greater movement by species. (Some innovative programs for establishing buffers around natural areas are described in box 5-F.) Although the concept of corridors is simple, establishing optimal corridors is a complex, controversial, and incompletely understood process. The size, shape, and location of corridors all affect their utility for any particular species. Furthermore, although corridors offer migration pathways for the native flora and fauna that are often the target of protection efforts, they can serve equally well as a conduit for the passage of invasive or opportunistic nonindigenous species Despite the potential problems and the considerable amount of research that remains to be done, corridors have already been established and used in a few cases, and the concept of linking natural areas is receiving increasing attention from land-management agencies and private organizations. For example, there are new linkages between the Oceola National Forest and Okefenokee Swamp in Florida and Georgia and an expanded network of corridor connections across Florida is under consideration (90).

In sum, setting aside a given amount of land in natural areas within the modern fragmented landscape does not alone ensure that the biological features for which they are valued will be preserved. To best conserve species, natural areas should include an array of ecosystems and the transition zones between them, which will allow for the many complex interactions that rely on links between different parts of the landscape.

SOURCES: P.L. Fiedler and S.K. Jain (eds.), Conservation *Biology: The* Theory and *Practice of Nature* Conservation, *Preservation,* and Management (New York, NY: Routledge, Chapman, and Hall, 1992); W.E. Hudson, Landscape *Linkages and Biodiversity* (Washington, DC: Defenders of Wildlife and Island Press, 1992); PKarieva et al. (eds.), *Biotic Interactions and Global Change* (Sunderland, MA: Sinauer Associates, Inc., 1993); D.A. Saunders, R.J. Hobbs, and C.R. Margules, "Biological Consequences of Ecosystem Fragmentation: A Review," Conservation *Biology,* vol. 5, March 1991, pp. 18-32.

Land Management, the National Park Service, and the Fish and Wildlife Service in the Department of the Interior. Each manages its own system of natural areas under its own mission. The National Wilderness Preservation System is managed by these four separate agencies and subject to varying management policies depending on which agency administers a particular Wilderness Area. To speak of one Federal system of natural areas as a single entity is, therefore, misleading.

The Greater Yellowstone Ecosystem, for example, comprises two National Parks, one National Parkway, six National Forests in two different Forest Service regions (four of which have designated Wilderness Areas adjacent to park boundaries), three National Wildlife Refuges, BLM lands, State lands, Indian reservations, and private lands. The entire area encompasses about 19 million acres and is referred to as the "largest single, essentially intact, functional 'natural' ecosystem" in the lower 49 States (92). The ecosystem has been able to support an abundance and diversity of wildlife because the land has remained relatively unfragmented. Maintaining a "whole" ecosystem depends on the condition of its parts. In recent years, increased visitor use, tourism, recreation, resource development (e.g., dam building and mining), timber harvesting, and air pollution have been posing threats to the ecosystem. Each landowner manages these stresses differently according to his or her own mission and as a result, the landscape is managed in isolated fragments that may not lead to effective protection of the entire ecosystem.

Problems that cross agency and ownership boundaries may not be addressed uniformly. Timber harvesting, construction, and heavy visitor use brought about by different management regimes can pose a threat to the large habitats required by some species, such as threatened grizzly bears, bighorn sheep, endangered peregrine falcons, and trumpeter swans, by disrupting the behavior and habitat of these species. A 1986 congressional evaluation of the Greater Yellowstone Ecosystem concluded that 'regional boundaries fragment the area into three [parcels].. . Even within the regions, individual unit boundaries often have little relevance to the Ecosystem. . . In virtually all agency decision-making, the whole is subordinated to its fragments" (122). In addition, efforts that do aim to coordinate management over the entire ecosystem either exclude important parties or are aimed at certain species, reflecting a fragmentation of coordinating bodies (122).

To help minimize landscape and institutional fragmentation and its consequences, there have been movements toward practicing more coordinated management under the existing agency structure with the goal of ecosystem management (see box 5-F). However, reconciling differing missions of agencies and interests of landowners

Box 5-F-Some Innovative Management Models: Toward Ecosystem Management in Natural Areas

As climate change begins to affect the plants and animals that reside on natural areas in the United States, managers may seek to establish buffer zones and migration corridors to continue protecting the living resources that these areas were designated to protect. Indeed, entire landscapes maybe required to accommodate range shifts. However, differing ownerships, management structures, agency missions, and jurisdictions often preclude management of areas larger than each individual management unit. Conserving biological resources is already becoming increasingly difficult because problems like pollution, development, and landscape fragmentation transcend management and ownership boundaries. Climate change is likely to compound these problems as yet another global-scale threat to some natural resources.

Within the past few years, land managers have recognized these problems and the need to address land and resource conservation on a larger scale. This relatively new concept for conservation has many names: ecosystem management, landscape management, cooperative management, integrated management, regional management, watershed management, or river basin management. Although no specific definition of this large-scale management concept has emerged, some generalizations can be made. Ecosystem, or landscape, management generally refers to the management of natural resources on a scale that crosses management boundaries and seeks to protect a variety of species and natural processes over the long term. Currently, no mechanism that effectively facilitates this kind of cooperative management on a large scale is in place. However, some programs are beginning to help bring some practical definition to the "ecosystem management" concept.

Many natural areas are located in regions where land is highly valued for economic uses, and attempts to expand protection around a natural area often conflicts directly with pressures for economic development. In many cases, especially in the eastern United States, land is simply no longer available. Thus, managers throughout the country have begun to explore new and innovative management strategies other than acquisition for balancing the needs of people who live and work near natural areas with t he needs of the ecosystems those natural areas aim to protect. In some cases, these strategies involve greater coordination among various Federal agencies that manage public lands; in other cases, they establish interactions between Federal land managers and local and private interests. In all cases, these strategies seek to bring together a diverse set of interested parties and harmonize conflicting needs before controversy erupts and complicates further action.

The Greater Yellowstone Ecosystem-As the first National Park (designated in 1872), Yellowstone has represented land-management leadership for the past century. Now, it is beginning to encompass a new management philosophy based on regional landscapes (64, 68). The Greater Yellowstone Ecosystem is a region under multiple ownership that scientists believe encompasses one of the largest and most important remaining ecosystems in the United States. Two-thirds of the 19 million-acre (7.7 million-hectare)[1] area is owned by the Federal Government: 2.5 million acres in Yellowstone and the Grand Teton National Parks, over 9 million acres in seven National Forests (nearly 4 million acres are designated as wilderness), and another million acres are managed by the U.S. Fish and Wildlife Service (FWS) and by the Bureau of Land Management (BLM). Over 6 million acres are State, private, and tribal lands. The region covers parts of t three States: Wyoming, Idaho, and Montana. Although each ownership and management scheme has its own philosophy and mission, regional issues such as wildfire and wildlife management are forcing these diverse groups together.

The Greater Yellowstone Coordinating Committee was created in the 1960s to address these issues. The committee includes regional and local representatives of the National Park Service (NPS) and the U.S. Department of Agriculture's (USDA's) Forest Service.[2] The historical distrust among the differing Federal agencies limited the

1 To convert from acres to hectares, multiply by 0.405.

2 Although the Fish and Wildlife Service and the Bureau of Land Management also hold land in the Greater Yellowstone region, they are not represented on the Greater Yellowstone Coordinating Committee. In addition, private landowners, Indian tribes, and State agencies holding land in the Greater Yellowstone Area are also not on the committee.

effectiveness of the committee and resulted in a Congressional report criticizing the committee-especially, the lack of coordination between the Forest Service andNPS(125). The committee was revitalized in the late 1980s after congressional threats of legislative reform and pressure from grass-roots organizations. The Committee then developed an integrated management plan (or "vision" document) for the Greater Yellowstone Ecosystem.

Proposals included using a "compatible management" approach in which the surrounding National Forests would essentially serve as buffers to the Park; however, diverse mandates of NPS and the Forest Service precluded any management plan that would make one agency's mission subservient to the other. Nevertheless, a report entitled Yellowstone Vision Statement was released in 1990 and outlined how interagency cooperation could lead to ecosystem management (48). Fierce opposition to the report by politicians, commodity groups, and private landowners was so intense that the 70-page report was re-released as an 1 l-page document that removed many of the original preservation and coordination themes (49, 114). Despite the failure to actually formulate an ecosystem-management strategy for the region, the fact that such an effort was undertaken is significant given the intense and almost war-like friction between environmentalists and members of the wide use movement (i.e., resource-development advocates) in this area. indeed, several obstacles to attaining cooperative management of the Greater Yellowstone Ecosystem remain. However, there is still hope that some consensus can be reached to protect the integrity of Nation's first National Park.

The New Jersey Pine Barrens-The New Jersey Pine Barrens is a unique region of habitat for rare and unusual plant and animal species that has remained largely undeveloped despite its proximity to New York City, Philadelphia, and Atlantic City. in the 1960s, proposals emerged to develop the area for retirement villages and jet ports (21). Forces aiming to preserve the area also grew (74). After several years of debate over how to best protect the resources and interests of the Pinelands, the Pinelands National Reserve was established in 1978. The 935,000-acre region is now managed by the Pinelands Commission, an intergovernmental (Federal, State, and local) authority with the responsibility to implement a regional plan "designed to guide development away from environmentally sensitive areas and into designated growth centers" (68). A variety of techniques is used to implement this plan, including imposing levels of restricted development according to a zoning system and using transferable development "credits" to help compensate landowners in restricted zones.

Early strategies for protecting the Pine Barrens recognized that acquisition by the Federal Government was not feasible because oft he high costs of direct purchase and because traditional uses such as agriculture, logging, and mining would have been disrupted. Early attempts by the State of New Jersey to form a conservation plan were perceived as pro-development and drew criticism from conservationists. Interest in a cooperative Federal-State effort grew. As a condition for Federal involvement, a Department of the Interior (DOI) task-force report challenged the State to increase its land and water conservation policies for the area (141). The State responded with a proposal for managing the area with a "graded" management scheme designed to protect the core of the Pinelands and also to provide an intermediate "buffer" area (1 00).

In 1978, the National Parks and Recreation Act (P.L. 95-625) became law and established the Pinelands National Reserve. However, the Federal Government had minimal authority to manage the reserve. A commission was established with representatives from county and State governments, private interest groups, and one DOI member to develop a Comprehensive Management Plan (CMP) for the area. Under the final protection and management plan, only 100,000 acres of key parcels were directly acquired by the State. Innovative incentives were employed to ensure flexibility in land use and equity among interests and to facilitate long-term protection. For example, a Pinelands Development Credit System was established to compensate landowners in areas with special zoning restrictions. Development credits can be sold to developers in designated growth areas, allowing them to build housing over the density limits specified in the CMP. In addition, local governments are compensated for lost tax opportunities through payments in lieu of taxes. Tax credits and special loan and grant assistance are also offered for management practices that promote land uses consistent with preservation of the reserve.

Because the Pinelands management scheme seeks to protect the region without placing excessive burdens

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Box 5-F-Some Innovative Management Models: Toward Ecosystem Management in Natural Areas--(Continued)

on any particular group, it has been called one of the most successful regional land-use-planning efforts in the United States and is to be regarded as a model for future protection efforts (99). Much of the success of this management scheme stems from the diverse methods used to protect the Preserve, the involvement and support of local residents, and the joint protection by the State and Federal Governments.

Unesco's Man and the Biosphere Program--The United Nations Educational, Scientific and Cultural Organization (Unesco) established the international Man and Biosphere (MAB) Program in 1970 to "develop a scientific basis linking the natural and social sciences for the rational use and conservation of the biosphere . . . and for the development of the relationship between humans and their environment" (73). This objective is realized through the establishment of an international network of Biosphere Reserves representing the wide range of the Earth's ecosystems. Although designation of an area as a Biosphere Reserve is purely honorary, cooperative management, research, and education are strongly encouraged and are seen as integral components of fulfilling MAB's mission. MAB Biosphere Reserves seek to correct fragmentation of the landscape by approaching research and management-training issues on a regional scale. Another purpose of the Biosphere Reserve program is to combat fragmentation of institutions and landownership by bringing diverse interests and disciplines together through education and research.

The Biosphere Reserves are generally composed of three regions in a Biogeographic *Area* (an area with distinctive biological, geological, and geographical characteristics).[3] These three regions are categorized as core areas, buffer zones, and transition areas. A *core area* is managed to preserve natural processes and genetic resources and is therefore usually under legal protection by the country (e.g., a National Park); a *bufferzone is* managed to minimize harm to the core area by human activity; and a *transition area is* where traditional land uses are found.

The U.S. component of the MAB program (U SMAB) was started in 1974, and 47 Biosphere Reserves have been designated thus far, covering 49 million acres (60, see figure). Five *directorafes* were formed to ensure interdisciplinary research in a variety of areas.[4] Most core areas are National Parks, Wilderness Areas, or areas under other legal protection (e.g., the Adirondack State Park in New York and the New Jersey Pinelands have been designated Biosphere Reserves). Although management of a region does not change once it has been designated a Biosphere Reserve, the various MAB committees facilitate integrated management through interdisciplinary, region-wide research and education projects. The intent is t hat these programs and projects will serve as catalysts for cooperative management. To help focus Biosphere Reserve activities, each USMAB directorate has a set of "interest areas" that include sustainable development, cooperative policy development, global change monitoring, and biodiversity protection (73).

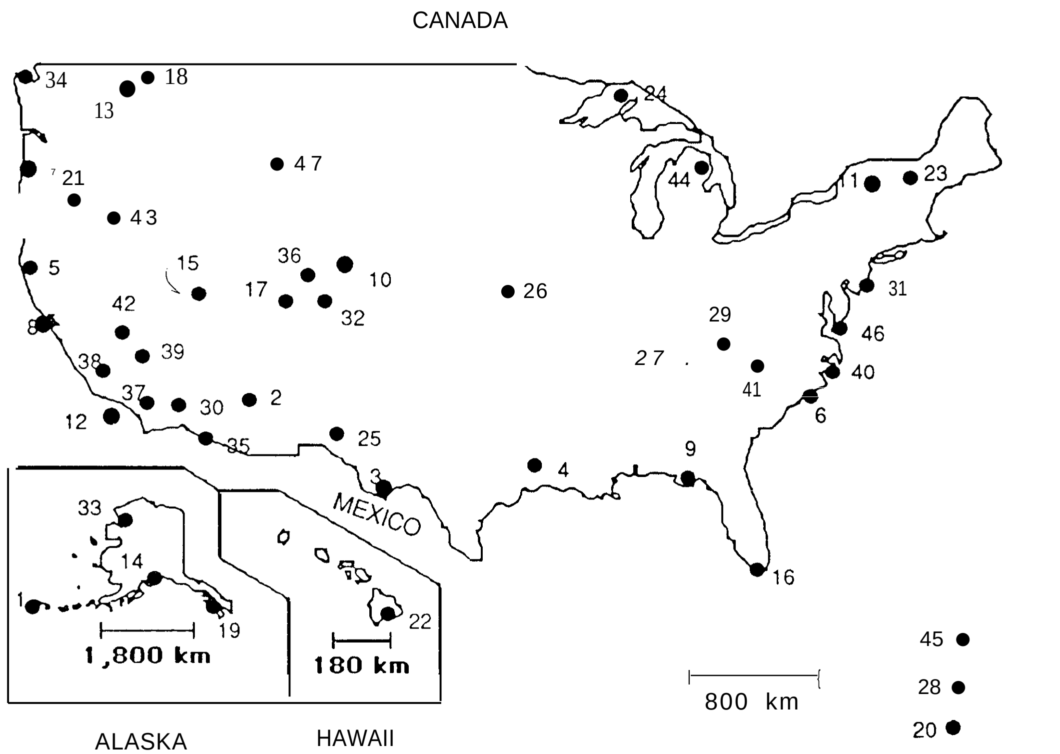
The Nature Conservancy's Last Great Places Initiative--The Nature Conservancy (TNC) is a private conservation organization, founded in 1951, with a mission to "preserve plants, animals, and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive" (118). In addition to owning and managing over 1,300 preserves covering over 1.3 million acres, TNC launched a new program, the Last Great Places Initiative, in May 1991, aimed at using a broader approach to protection efforts by protecting entire ecosystems-not just isolated species.

Twelve sites, ranging in size from 40,000 to 11 million acres and spread around the country, are currently included in the program, which has the potential of growing to 40 or more sites in the future. The sites are chosen

3 Biosphere Reserve is the term used in official MAB documents. The distinction between Biosphere Reserve and Biogeographic Area is that a Biosphere Reserve is a site that has been explicitly designated by Unesco whereas a Biogeographic Area is a more conceptual term referring to an area exhibiting a given set of biological and geological characteristics. However, the terms are sometimes used interchangeably.

4 The USMAB directorates are: High Latitude Ecosystems, Human Dominated Ecosystems, Marine and Coastal Ecosystems, Temperate Ecosystems, and Tropical Ecosystems (73).

Biosphere Reserve Sites In the United States



EuroMAB DIRECTORY			**UNITED STATES**
1. Aleutian Islands	13. Coram	24. Isle Royale	36. Rocky Mountain
2. Beaver Creek	14. Denali	25. Jornada	37 San Dimas
3. Big Bend	15. Desert	26. Konza Prairie	38. San J
4. Big Thicket	16. Everglades	27. Land Between the Lakes	Canyon
5. California Coast Ranges	17. Fraser	28. Luquillo	40. South-Atlantic Coastal Plain
6. Carolinian-South Atlantic	18. Glacier	29. Mammoth Cave Area	41. Southern Appalachian
7. Cascade Head	19. Glacier Bay-Admiralty Island	30. Mojave and Colorado Deserts	42. Stanislaus-Tolumne
8. Central California Coast		31. New Jersey Pinelands	43. Three Sisters
9. Central Gulf Coastal Plain	20. Guanica	32. Ntwot Ridge	44. University of Michigan
10. Central Plains	21. H.J. Andrews	33. Noatak	45. Virgin Islands
11. Champion-Adirondack	22. Hawaiian Islands	34. Olympic	46. Virginia Coast
12. Channel Islands	23. Hubbard Brook	35. Organ Pipe Cactus	47. Yellowstone

SOURCE: National Park Service, 1993.

in part because they contain: 1) high-quality examples of terrestrial or aquatic communities that are endangered or inadequately protected, 2) concentrations of rare species, 3) a large, relatively undisturbed example of a natural community once characteristic of its ecoregion but now fragmented or degraded, or 4) a critical migratory stopover point or corridor (14). The management concept for these bioreserves is not unlike that of the MAB Biosphere Reserve concept: a core natural area is managed for preservation and is surrounded by a buffer zone with land uses managed to minimize harm to the core area. Like MAB Biosphere Reserves, core areas are generally under legal protection as a park or wilderness. However, TNC'S approach differs from MAB's in that inactively negotiates with local landowners to develop a plan to protect the core area while accommodating community growth.

TNC envisions using several protection measures including Habitat Conservation Plans, which have been used in other TNC efforts to protect endangered species. For example, the Balcones Canyonlands Conservation

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Box 5-F-Some Innovative Management Models: Toward Ecosystem Management in Natural Areas-(Continued)

Plan was developed by environmentalists, developers, local government officials, and Federal agency personnel to protect seven threatened and endangered species and other rare plants in the area and to fend off the threat of habitat fragmentation.[5] A 65,000-acre preserve was created near Austin, Texas, with about 30,000 acres to be managed by FWS as a National Wildlife Refuge and the rest acquired by and/or managed in cooperation with local industries. Acquisitions will be funded by a combination of Federal, State, and local grants as well as by private contributions. In addition, an impact fee imposed on new construction in designated areas will provide additional revenues.

The Nature Conservancy's Last Great Places Initiative seeks to coordinate and balance very diverse interests in order to preserve environmentally important regions that transcend ownership boundaries through various incentives and agreements. As a result, it represents yet another innovative approach to land management that does not require government ownership.

New York's Adirondack Park—This 6 million-acre State Park Consists of a 2.6 million-acre Forest Preserve established in 1885 and additional land under both State and private ownership added in 1892. The Park is protected indefinitely by Article XIV Section 1, of the New York State Constitution. It is the largest State Park in the continental United States and the largest single forested area east of the Mississippi, and it represents one of the most significant hardwood ecosystems in the world. Protection of the area was prompted by timber harvesting and other activities over a century ago and has been strongly supported until very recently (68).

The Adirondack Park Agency (APA), created in 1971 by the State of New York manages the development pressures on public and private lands in the park. It set up a zoning system in its 1973 *Land Use and Development Plan* that resembles the core and buffer idea with designations and density limits ranging from "resource management areas" (with most protection of naturalness) to "hamlets" (population and commercial centers) (173). Although APA established the density limits in the six land-use areas, actual control, enforcement, and implementation of the plan lies with the local communities. As of 1990, only 11 of the 105 communities in the region had developed zoning plans because of resistance to restrictions that would limit private-property rights.

Now, a century after the park was established, development pressures are threatening park protection. Projected growth trends would fragment about 3 million acres of the park and increase the park's population fivefold (68). A commission was established by New York Governor Mario Cuomo in 1989 to study implications of these pressures on t he park. The commission recommended a new administration for the park that would have broad authority over land use and development with a focus on limiting fragmentation. The commission also advocated the use of corridors to link the Adirondack natural community with those of the northeastern United States and Canada and it recommended that "the processes which maintain habitats most likely to be affected or lost through climate change should be determined" and that mechanisms to ensure their perpetuation be investigated. However, it is estimated that implementing the plan would cost at least $15 million annually, with proposed funding from luxury-home taxes and user fees. Not surprisingly, many residents and local governments strongly oppose the commission's recommendations.

Although tension between diverse interests is growing over future management of the Adirondack Park are% the management ideas first suggested by APA incorporated some of the novel methods (e.g., graded protection through zoning) that seem successful in other areas, such as the New Jersey Pinelands. If the residents of the

5 The Balcones Canyonlands Conservation Plan is a Habitat Conservation Plan required under the Endangered Species Act (see box 5-D). The threatened and endangered species that the plan seeks to protect Include two species of migratory songbird—the black-capped vireo and the golden-cheeked warbier, and five species of invertebrates that have adapted to the unique cave environment-one spider, two types of beetle, a "pseudo" scorpion, and a daddy longlegs (10).

Adirondack Park region and other interested parties can jointly support a conservation goal for the region, efforts for coordinated management may find greater success.

The Northern Forest Lands Study—As a result of rising land values and development pressures in New England's forests, the governors of New York, Vermont, New Hampshire, and Maine appointed a Governors' Task Force on Northern Forest Lands in 1966 to study the status and trends of roughly 26 million acres of their States' forests with the help of the USDA Forest Service. The resulting report proposed several strategies for maintaining undeveloped areas of private forest lands while keeping them open to the public (53). A variety of protection measures was evaluated, including zoning, conservation easements, acquisition, and tax incentives. In essence, the report challenges the States to find a common vision and to take the lead in developing a regional protection plan for the area by encouraging the States and the Governors' Task Force to evaluate the region's resources and to develop strategies for their protection in the future. It also includes a proposal for Federal assistance in these planning efforts and for purchasing key parcels of land.

In 1990, the Northern Forest Lands Council was established to continue the Northern Forest Lands Study for another four years. This council will further develop the themes and challenges raised in the report and present a set of specific recommendations to the New England States and to Congress by the fall of 1994.

Because the 1990 report favors a variety of protection measures and cooperation among differing ownerships, a "pinelands-like" management model may emerge from future negotiations. If successful, the coordinated-management effort will be among the largest because of the degree of interstate cooperation required in an area 25 times the size of the Pinelands National Reserve.

Glacier National Park Biogeographic Area, Crown of the Continent Project—This research and education project represents an attempt tore-integrate a fragmented landscape by "creat[ing] and implement[ing] a coordination process and the necessary facilities to achieve a quantitative understanding of the natural and human environment of the Crown of the Continent Ecosystem" (36). This idea is similar to the MAB approach in that integrated, regionwide research and education will ideally lead to better-coordinated management of the region. The "crown of the continent ecosystem" includes Glacier National Park, the Bob Marshall/Great Bear-Scapegoat National Wilderness complex, and surrounding Indian Reservations and private land. An Ecosystem Center, administered by an independent board of directors, would fill five specified roles: policy exploration, basic research, monitoring and database management, ecosystem interpretation, and education (36). The activities of the Ecosystem Center would generate an integrated and reliable source of information for various management decisions. In addition, various advisory councils (representing interest groups, tribal governments, Federal and State agendas, and local landowners) are envisioned to help facilitate communication and cooperation. There are already significant efforts under way to begin to synthesize information for decisionmaking. Both Glacier National Park and Flathead National Forest maintain well-developed Geologic Information Systems that could contribute to better cooperative management. Although this project has not yet been funded or implemented, the ideas embodied in its proposal illustrate yet another way to begin to consider landscapes as a whole without undermining the owners and management regimes of individual parcels.

Rio Grande Basin Consortium-Although not directly targeted at natural areas, the Rio Grande Basin Consortium (RGBC) is a recent attempt to engage disparate public agencies and private interests in a multidisciplinary effort to conduct research and share information aimed at improving planning for the river basin. The consortium was launched in 1990 after a well-attended and enthusiastic conference held in Albuquerque on global climate change scenarios for the basin, "The Rio Grande Basin: Global Climate Change Scenarios." RGBC'S goals are to serve as a clearinghouse of environmental, social, and economic information on the region, to match researchers with suitable projects and increase the effectiveness of those projects through greater coordination, to provide a forum for interaction through means such as conferences and newsletters, and to translate knowledge and guide planning in ways that will promote the sustainable development of the area's

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Box 5-F-Some Innovative Management Models: Toward Ecosystem Management in Natural Areas-(Continued)

resources (166). Members of RGBC'S steering committee include representatives from the Forest Service, the Bureau of Reclamation, NPS, the U.S. Army Corps of Engineers, and the U.S. Geological Survey, as well researchers from the University of New Mexico, New Mexico State University, and New Mexico Tech and officials from local agencies ranging from the City of Albuquerque to the Indian Health Service. The consortium is also exploring the possibility of working with the Houston Area Research Center to address Rio Grande issues on both sides of the U.S. border. Although not directly linked to land management, RGBC'S activities are designed to further protect the biological resources of the Rio Grande while at the same time meeting the needs of the diverse cultural groups that inhabit the basin area.

SOURCE: RJ. Lilieholm, *Preserves at Risk An Investigation of Resource Management Strategies, Implications and Opportunities,* contractor report prepared for the Office of Technology Assessment, January 1993.

is not easy and will require unprecedented leadership and vision. The Yellowstone area is not unique-institutional fragmentation threatens ecosystems throughout the United States. Some innovative first efforts are in place that aim to minimize both landscape and institutional fragmentation for ecosystems or habitat areas. Although the effectiveness of these cooperative management schemes is sometimes limited by competing interests, the schemes signify promising frost steps toward innovative solutions to fragmentation problems.

Human Impacts

In addition to the different types of fragmentation that impinge on natural areas, numerous other threats exist within and outside their boundaries. Within designated natural areas, damage from overuse and overcrowding by tourists and recreationists is often cited as a major concern, especially with respect to long-term impacts and future management (76). These activities may destroy vegetation and cause erosion that disturbs wildlife habitat. Increased exposure to human activity can disrupt breeding and modify animal behavior. Other activities in federally protected natural areas such as cattle grazing and boating can increase water pollution, facilitate the spread of exotic species, damage habitat (through erosion and agitation of water), and disrupt nesting. For example, power boating and water skiing allowed on Des Lacs National Wildlife Refuge in North Dakota during the 1980s has been found to directly disturb migratory bird nesting and broods of newly hatched chicks-the refuge's primary purpose (163). Grazing cows in the Browns Park NWR in Colorado disturb the habitat of geese and ducks by eating the vegetation necessary for bird habitat (163). The cumulative effect of these various threats can lead to the decline of sensitive species that the reserves aim to protect and increase the proportion of species that are tolerant of landscapes disturbed by humans (44, 56).

A survey of managers of the Fish and Wildlife Refuge System concerning the harmful effects of secondary uses on the primary mission of refuges found that at least one harmful use was occurring on 59 percent of the refuges. Harmful uses included public use (camping, hunting, boating, and off-road-vehicle use), economic use (grazing, logging, commercial fishing, and mining), and military use (air and ground exercises). For example, airboats were considered harmful on 69 percent of the refuges where airboat activity takes place, and beach use and swimming were considered harmful on 41 percent of the refuges where beach use and swimming occur. More than one harmful use was occurring on several refuges (163).[13] These activities can disturb wildlife directly or indirectly by disturbing their habitat. Resource damage from recreational activities such as erosion caused by hiking and camping has led to diminished wilderness character in one of every four Wilderness Areas according to a 1988 Forest Service survey (93). Several reports on the state of National Park resources cited visitor use, consumptive uses, vehicle noise, soil erosion, and invasion of exotic species as among the most common internal threats to native vegetation, animal habitat, and other resources (17, 154). The larger National Parks, including Yosemite, Yellowstone, Glacier, Great Smoky Mountains, the Everglades, and those designated as Biosphere Reserves, endure over 30 different human-caused internal and external threats (17)--over twice as many as the NPS-wide norm (52).

Because internal stresses canto some extent be regulated by the designated agency, they are generally less threatening than external stresses, which cross agency and ownership boundaries and often fall out of the purview of agency influence. The primary external threats include encroaching development, air and water pollution, logging, encroaching exotic plant species, fire, poaching, livestock grazing, and military air exercises (93). These activities have the potential to alter the natural processes in protected areas, contribute to erosion, damage habitat and scare wildlife, and contribute to a decline in biodiversity in protected areas, especially for species sensitive to human disturbance (45, 87). For example, resources in the Everglades National Park have been severely affected by herbicides, pesticides, and fertilizers in the agricultural runoff water that feeds into the park. In Yosemite National Park, a buildup of Calthane (an agricultural pesticide) in the bodies of endangered peregrine falcons causes a weakening of their egg shells and makes them unable to breed in their third to fifth year (154). Also, Kesterson National Wildlife Refuge in California is threatened by selenium toxicity from agricultural runoff (see vol. 1, box 4-E). The sonic booms and low-elevation flybys associated with military air exercises over the Cabeza Prieta NWR in Arizona are believed to adversely affect the fawning and calving of Sonoran pronghorn antelope and desert bighorn sheep (163).

Water conflicts can also constitute a threat to natural areas, especially in the arid West, where water allocation is determined by the prior appropriation doctrine (see vol. 1, ch. 5). Under this doctrine, those who first put water to a certain use obtain a‘ ‘right’ to use the water. The conflict over water surrounding the Stillwater National Wildlife Management Area, described in box 5-G, shows the complexity of water-allocation issues. Unfortunately, water rights under State law for wildlife and fish and other environmental benefits are very junior (where they exist at all), making water supplies dependent on those who hold more senior rights. Securing adequate water for Federal natural areas by claiming Federal water rights (and overriding the State priority system) is a continuing point of debate (see box 5-H).

The cumulative effect of landscape fragmentation, institutional fragmentation, and other threats has taken its toll on federally protected natural areas. In a recent survey, only around one-third of all National Park units reported their resources in “good” condition (154). Although similar surveys have not been conducted for other Federal natural areas, there are indications that multiple stresses are degrading them (159, 163). Climate change may only intensify these existing threats to resources, especially in the arid West, where water is already a scarce resource.

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13 FWS has only partial authority over mineral-resource-development and military activities on some refuge lands because authority Over these resources often falls under the jurisdiction of other agencies (145, 163).

Box 5-G-Competition for Water: The Case of the Stillwater National Wildlife Management Area

Wildlife refuges occupy a precarious position in the arid West. Most refuges are centered around water bodies--rivers, lakes, or marshes-but competing human demands for water have significantly reduced the amount of water that actually remains in streams to flush through and replenish refuges. A study by the Bureau of Reclamation on refuge water supplies and needs in the central valley of California found that only one refuge[1] has a firm supply of water “in the amount considered necessary for proper management of existing wetlands and facilities within the refuge boundaries” (142). If, as most climate models predict, the interior Western States become hotter and drier due to climate change, Western refuges could themselves become threatened with extinction (see chs. 2, and 4 and vol. 1, ch. 5).

Water has long been a precious commodity in the arid West. Scarce water flows from rivers and streams are in high demand by farmers and urban residents, who seek to dam, divert, and pump water into *offstrearn uses,* such as irrigation and municipal water supplies. At the same time, the maintenance of fish and wildlife habitat, as well as traditional uses by Native Americans and recreational uses by Western residents and tourists, relies on protecting *instream* flows--that is, keeping a certain minimum volume of water flowing through streams year-round (the necessary volume depends on the type of habitat or use to be maintained). A complex legal structure has grown up over the past century to mediate hotly contested battles over who gets water, and how much each party gets. The legal doctrine for water allocation that has prevailed in the West is one of prior *appropriation,* which means that those who historically used the water first have the highest priority in claiming present water supplies for continuing use? Ironically, fish and wildlife habitat and traditional uses by native Americans were the initial uses of most Western rivers in their natural conditions, yet these uses have rarely been quantified or been allocated water; if water has been allocated to these uses, the rights are often considered junior to agricultural and municipal claims.

The case of the Stillwater National Wildlife Management Area (NWMA) and Pyramid Lake in the Truckee-Carson River basins illustrates the complex conflicts among competing human and natural area uses for water, and suggests that the situation for refuges may worsen if climate change intensifies the squeeze for Western water. The Truckee River originates in the Sierra Nevada Mountains. It is the only outlet of Lake Tahoe and flows northeast from the lake through California and Nevada to drain into Pyramid Lake in northwestern Nevada (see figure). The Carson River originates southeast of Lake Tahoe, near the California-Nevada State line, and flows roughly parallel to the Truckee River to empty into a marshy area known as the Carson Sink. The Stillwater NWMA was established in this area in 1948 and offers food and habitat to bald eagles, American white pelicans, and numerous species of waterfowl. A dam upstream of Carson Sink created the Lahontan Reservoir, which has diminished the flows to Stillwater Marsh and other wetlands in the Sink. A canal connecting the Truckee and Carson Rivers was constructed in 1905 as part of the Bureau of Reclamation’s Newlands Project to supply water for irrigated agriculture.

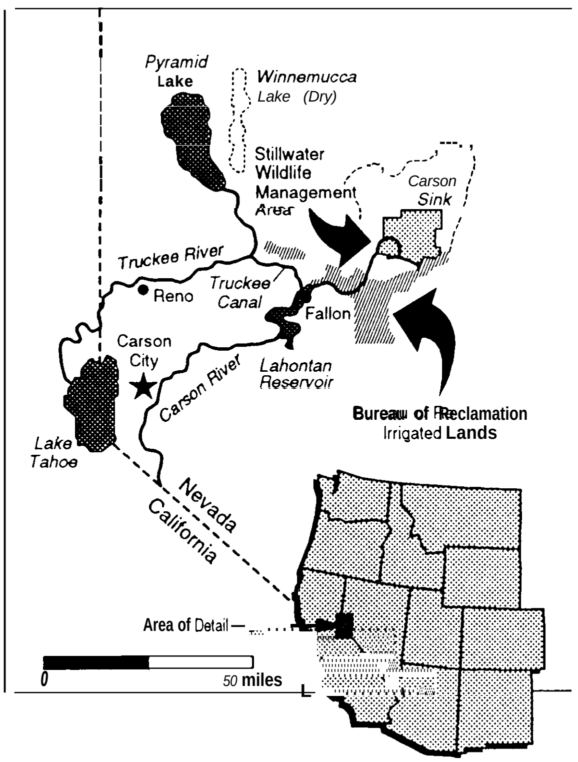
Four major users compete for water from the Truckee and Carson rivers: l) farmers served by the Newlands Project, 2) Native American tribes, 3) Reno-area residents, and 4) the wetland ecosystem. The Newlands Project which includes the Truckee Canal, is used by farmers to irrigate some 63,100 acres (25,600 hectares)[3] down-

1 In the study, 15 refuges were considered: 10 National Wildlife Refuges, 4 State Wildlife Management Areas, and 1 privately managed wetland area within the central valley hydrologic basin of California.

2 For example, if farmers occupying an area near a dam and reservoir have traditionally pumped 10,000 gallons (9,500 liters) a year for irrigation and a nearby municipal area has only recently begun pumping from the reservoir, the farmers would receive their water allocation first in drought years, when the reservoir might not be abfe to supply all claims on the water.

3 To convert acres to hectares, multiply by 0.405.

Stillwater National Wildlife Management Area



SOURCE: National Research Council, 1992. (Reprinted with permission from R.E. Morns, Permissions Managers, National Academy Press, Aug. 31, 1993.)

stream of the Truckee canal and around the lower Carson River. Until tribal lawsuits forced a change in operations in the 1980s, the project diverted more than half the flow of the Truckee River, which diminished water levels in Pyramid Lake and completely desiccated nearby Winnemucca Lake. The project also diverted water from the Carson River, which reduced the flow to the wetlands in Carson Sink. Two different Native American tribes with claims for water rights have been affected by the Newlands Project The Pyramid Lake Tribe has long maintained a traditional fishery downstream of the Truckee Canal on the lower Truckee River and in Pyramid Lake. The Tribe argues that the lake should be maintained at its historic levels to support the fishery as well as to protect the cui-ui, an endangered fish species that the tribe considers sacred. The Fallen Indian Reservation is on the Carson River side of the Truckee Canal. The reservation contends that the irrigation water it was promised in exchange for surrendering most of the reservation lands when the Newlands Project was constructed has never been delivered. The tribe wants water in order to sustain agriculture on the reservation. Municipal users in the fast-growing Reno metropolitan area on the Truckee River upstream of the Canal continue to clamor for more water from the Truckee because local groundwater can provide only about one-fifth of the municipal demand. Despite storage at several reservoirs upstream of the city, there is not enough water to maintain normal flows to the city in the event of a 2- or 3-year drought.

Finally, there are the needs of wetlands and wildlife. It is estimated that before human settlement wetlands covered more than 85,000 acres in the Carson Sink (including the Stillwater wetlands), while separate wetlands surrounded Pyramid Lake and Winnemucca Lake. Water diversions to operate the Newlands Project have threatened the entire system. On the Truckee River side, completely drying out Winnemucca Lake destroyed aquatic and wetland habitat. Water diversions also lowered the water levels in Pyramid Lake, which allowed the formation of a delta that blocks spawning of the threatened Lahontan cutthroat trout and diminishes habitat for the endangered cui-ui. On the Carson Riverside, water diversions diminished the Stillwater Marsh and surrounding wetlands to 40,000 acres over several decades. Despite diminished water flows, the Stillwater wetlands still play a critical role in protecting waterfowl and migratory birds. They support 90 percent of the Nevada snow goose population during part of the year, as well as thousands of white pelicans and tundra swans. Half the population of canvasbacks ducks on the Pacific Flyway pass through Stillwater NWMA, as well as one-third of the dowitohers (a Water bird similar to snipes and sandpipers). Stillwater also harbors one of the world's largest nesting colonies of white-faced ibis (1 18).

*(Continued on **next page)***

Box 5-G-Competition for Water:
The Case of the Stillwater National Wildlife Management Area-(Continued)

Ironically, efforts starting in the 1960s to improve the operating efficiency of the Newlands Project in order to conserve water for tribal claims, restore Pyramid Lake, and protect the cui-ui and cutthroat trout have further diminished the Stillwater wetlands. After water flows from the Carson River had been diverted, runoff from agricultural fields became a major water source for the marsh. As improved efficiency cut the amount of runoff, more wet!ands dried out. The various water diversions, combined with recent droughts, have reduced the marshes in the Stillwater NWMA to an area of only 4,000 to 6,000 acres. In 1989, The Nature Conservancy purchased water rights on 150 acres of marginal farmland to support Stillwater conservation efforts, but that supplied only a fraction of the water needed to restore the area.

The conflict over water in the Truckee-Carson, which started early in the century, grew to such proportions that Congress finally stepped in to help negotiate a settlement. The Truckee-Carson-Pyramid Lake Water settlement Act (P.L. 101-618), passed in 1990, established a new allocation of water rights that attempts to balance the competing uses and claims for the water. The act will allow water to be reallocated from agricultural to other uses by increasing the operating efficiency of the Newlands Project and by retiring up to 23 percent of the agricultural land it serves. Municipal users will be able to purchase water rights from agricultural users. Congress authorized the Fish and Wildlife Service to purchase water rights from willing sellers in amounts sufficient to maintain 25,000 acres of Stillwater wetlands in perpetuity.

Stillwater NWMA does not yet have all the water it needs, but at least there is now a mechanism for acquiring it. A drier climate linked to greenhouse warming could delay, or even prevent, the restoration effort because drought conditions would likely lead to increased demands for agricultural and municipal water conversions. If conditions become dry enough, however, water prices may rise high enough to drive some adjacent farmlands out of production, potentially freeing some water supplies. On the other hand, if urban growth in Reno continues at the present rate, municipal uses could well absorb any water released from agriculture. Indeed, in the event of a prolonged drought in which water supplies become critical, demand for municipal water could challenge the legislative settlement that now supplies Stillwater wetlands with water rights.

The distribution of limited water among competing uses will continue to be a complicated and controversial task as the climate changes. “The West is defined . . .by inadequate rainfall,” notes Western author Wallace Stegner. “We can’t create water, or increase the supply. We can only hold back and redistribute what there is.” Congress has intervened to ensure that at least some water will remain to nourish 25,000 acres of Stillwater refuge wetlands in perpetuity. Whether other western refuges will reap any rewards from similar redistribution remains to be seen.

SOURCES: National Research Council, *Water Transfers in the West: Efficiency, Equity, and the Environment* (Washington, DC: National Academy Press, 1992); The Nature Conservancy, “Turning on the Tap at Stillwater,” *Nature Conservancy*, vol. 40, July/August 1990, pp. 28-29.

THE PROBLEM OF CLIMATE CHANGE: A SHIFTING CLIMATE OVER A STATIC MAP

The conditions that accompanied natural climate changes in the past are significantly different from those expected to accompany human-induced climate changes in the future (see ch. 2). Climate zones are expected to shift significantly at unprecedented rates during the next century. A warming of 5.4 °F (3 °C) by the year 2100 could shift optimal climate regimes for some species roughly 200 to 300 miles (300 to 500 kilometers)[14]

14 To convert miles to kilometers, multiply by 1.609.

Box 5-H-Water and Natural Areas Under Climate Change

Water is important for natural areas for a variety of reasons. More than 75 percent of wildlife and fish species in the arid West depend on riparian (riverside) habitat at some point in their lives (43, 140). The Nation's dwindling wetlands (including those in riparian areas), which provide critical habitat for popular game and many endangered species and numerous services such as flood control, depend on adequate water flows (see vol. 2, ch. 4). In addition, instream water flows have become a primary concern for many types of outdoor recreation such as recreational fishing, waterfowl hunting, canoeing, shoreline camping, and sightseeing (15, 110).

For example, the wetlands in California's central valley provide essential habitat for migratory birds, resident wildlife, and several threatened and endangered plant and animal species. These wetlands contain 10 National Wildlife Refuges, 4 State Wildlife Management Areas, and several privately managed wetlands and are a critical part of the Pacific Flyway, a migratory route ranging from Mexico to Canada (142). Over 10 million waterfowl and other migratory birds pass through the Central Valley wetlands every year (142). Water supplies are controlled by dams and water-delivery systems. Water withdrawals and diversions for agriculture and other development activities have reduced the wetlands in this area from over 4 million acres to roughly 300,000 acres (1.6 million to 122,000 hectares)[1] (142). Biologists stress that unless a dependable supply of water is maintained, waterfowl and wildlife could significantly decline (142).

Climate change and water supplies-If climate change leads to drier conditions, pressures to divert water to sustain growing cities and agriculture could contribute to additional habitat decline, increased species losses, and reduced recreational opportunities. Efforts to secure water for fish and wildlife and other environmental purposes have increased in recent years. Securing water rights for Federal natural areas would help ensure that the functions of these areas are not sacrificed in the future and are given consideration in times of water shortage.

Water rights and Federal natural areas-Water rightsfor Federal natural areas can be obtained at the State or Federal level. Most States have passed laws that recognize instrearn flows for the benefit of fish and wildlife as a legitimate "beneficial use" under the prior appropriation doctrine in the West (see vol. 1, ch. 5, for more details). The Federal Government Can try to secure water for the benefit of fish and wildlife by obtaining water rights under State law just as any other landowner in a State can. However, unless purchased from more-senior rightsholders, these rights would be junior, meaning they would be among the first to be sacrificed under extreme situations (123). Water law also varies considerably from State to State. Instream flows can also be considered under the National Environmental Policy Act (P.L. 91-190), under the Endangered Species Act (P.L. 93-205) (during critical habitat designation), while acquiring State permits, or relicensing darns (1 10).

Normally, the allocation of water is determined by State water law, but the Federal Government has exercised its power to claim "implied" water rights for "lands withdrawn from the public domain and reserve[d] for a federal purpose" *(Cappaert v. United States as cited* by 123). Consideration of the purposes for which the land was reserved and whether water is necessary to carry out those purposes are important factors in determining whether Federal water rights were indeed "implied" when the land was reserved. Under this rule, only lands reserved from the public domain are eligible for Federal reserved water rights; lands purchased or otherwise acquired by the Federal Government from outside the public domain are not eligible. In addition, only unappropriated water can be claimed, the right is prioritized by the date of the reservation, only water sufficient to carry out Federal purposes Is granted under the right, *and* the right is lost if it is not put to immediate use (123).

Because they were reserved from the public domain, Federal water rights maybe claimed for most National Parks. Even though the National Park Service states that it "will assert claims to reserved federal water rights for water quantities determined to be the minimum amounts needed to protect the primary purposes of a given park" (153), these rights have not been quantified for most National Parks, and there is no policy or program in place to quantify necessary instream flows (110).

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1 To convert acres to hectares, multiply by 0.405.

(Continued on next page)

Box 5+1-Water and Natural Areas Under Climate Change--Continued)

Although it is a matter of considerable controversy, Federal water rights are currently not reserved for Wilderness Areas because it is not dear whether they are areas "reserved" for a Federal purpose or simply a special management designation. In addition, it is debated whether the creation of water rights is necessary to carry out the purposes of the Wilderness Act (P.L. 88-577) (123). Water rights for most of the early Wilderness lands were not an issue because many of these areas included headwaters, and, therefore, water supplies were not at risk from upstream diversions. However, recent and potential future designations include areas in the arid West that lie downstream from other water users. Increased demands for water from population growth of climate change could increase pressure to divert water that now feeds Wilderness areas and could escalate the debate surrounding water rights for Wilderness Areas.

In many cases (especially in the West), the Fish and Wildlife Service has acquired water rights for National Wildlife Refuges with land purchases and applied for rights under State law (147). However, these rights are often very "junior" or of low priority compared with those of other water-rights holders, and they are subject to varying State water laws. As a result sufficient water may not reach a refuge in water-stressed times. In addition, the water flowing into many western refuges is in upstream reservoirs that are controlled by other agengies or subject to certain Iimits that dictate the amount of water available to the refuge. Federal water rights have been reserved for some refuges. Currently, 78 refuges west of the Mississippi River have Federal reserved water rights, but these rights have not been quantified for most refuges (147).

Unlike other laws governing natural areas, the Wild and Scenic Rivers Act (P.L. 90-542) expressly claimed Federal water rights in the amounts necessary to preserve the values for which the rivers were designated, and authorized condemnation of existing rights, if necessary, to carry out the act. However, to date, no designation of a river has included the condemnation of existing water rights (123).

SOURCE: Office of Technology Assessment, 1993.

northward and 1,600 feet (500 meters)[15] upward in elevation (58, 94). In response, plants and animals may either migrate to more suitable locations, adapt to new climate conditions, or decline and possibly face extinction (see box 2-E) (91, %). Groups of species will not all respond the same way, so the species composition found in any given area will likely change (46, 172).[16] Climate conditions for which some species are best adapted could shift out of natural areas that are now protected and into adjacent (or even distant) areas that are more developed, fragmented, or subject to different management regimes. However, although climate zones and ecosystems may shift in response to climate change, the legislatively established boundaries of protected natural areas are generally fixed (see fig. 5-l).

• Vulnerability

Natural area vulnerability to climate change depends largely on why the area is **valued** and on the nature of the existing complex interactions among climate and ecological systems. Therefore, although some general risks can be identified, it is difficult to determine exactly which

15 To convert feet to meters, multiply by 0.305.

16 Though it is not clear exactly how species will respond to a change in their optimal climatic regime, paleoclimatic evidence and modeling analysis suggest that species may migrate at different rates, and that some species may not be able to migrate or adapt to new conditions fast enough (40, 46, 172).

federally protected natural areas are most at risk from climate change. Protected areas established primarily to protect unique geologic features such as cliffs, gorges, or canyons-the Grand Canyon National Park and the Craters of the Moon National Monument, for example-are not immediately vulnerable to changes in temperature, moisture, and carbon dioxide (CO_2) concentration (81).17 However, some of these areas are also valued for their vegetation and wildlife. Natural areas valued for wildlife protection, biodiversity conservation, and wildlife-related recreation are vulnerable to climate change to differing degrees depending on the sensitivity of species to climate change; the number of species the area protects; the amount of human disturbance in the area; the size, shape, and environmental diversity of the area; and the nature of surrounding lands.

The disparity between shifting ecosystems and stationary natural area boundaries places protected natural areas at risk in three distinct ways: 1) the character of an area could change, 2) biodiversity and endangered species could experience diminished protection, and 3) the quality of other services, such as recreation, may be diminished. These three types of changes may occur to varying degrees on different natural areas. Areas that are small, long and narrow (exposing more "edge" relative to the area protected), and unbuffered; areas already under significant stress; or areas with rare or climate-sensitive species will be more vulnerable to climate change. Many studies (28, 58, 97, 161) have determined that coastal ecosystems, alpine ecosystems, arctic ecosystems, and mid-continent wetlands may be particularly vulnerable to climate change because these areas are sensitive to sea level rise, temperature change, sea-ice melting, and drought.


N. CUTLER

Arches National Park, in Utah, pays tribute to the geologic history of the West. This unique desert ecosystem is greatly influenced by weather and climate extremes.

Changed Character

Plants and animals make up an essential part of the scenic and recreational values of natural areas-bighorn sheep and alpine flowers are part of the attraction of Roe@ Mountain National Park in Colorado, while a distinctive array of resident and migratory waterfowl makes the Ding Darling National Wildlife Refuge on Sanibel Island in Florida one of the most popular natural tourist attractions in that State. Even in a constant climate, biotic processes that have shaped these areas are not static, but these changes generally occur much more slowly than those projected to occur under climate change (see ch. 2). As a result, climate change may threaten the distinctive character of many natural areas, particularly those set aside for ecological attributes, as species move in and out of fixed natural area boundaries. To the extent that a distinctive character is valued, more intensive management measures may be required to maintain the ecological conditions for some species or habitats. On the other hand, it may not be possible or may eventually become too costly to maintain certain species and habitats over the long term regardless of management intensity.

17 Climate conditions do play an important role in the long-term processes of erosion that have shaped the Grand Canyon, but that is on a geological rather than a human time scale.

Dimikshed Protection of Biodiversity and Endangered Species

Many natural areas are already islands in a sea of development and human activity. The landscape outside protected natural area boundaries may be fragmented and offer little suitable habitat for species able to migrate. Moreover, if few habitat types are available within the preserve, then species have even fewer alternatives as climate changes (89). As a result, some species may decline in number or become extinct. Although not necessarily designed specifically for the protection of species and biodiversity, the Federal system of natural areas now plays a big role in protecting habitat for rare and endangered species and preventing additional species loss and decline. Species that leave the boundaries of protected natural areas in their attempts to find suitable climate may no longer be protected. Thus, to the extent that federally protected natural areas are valued for nurturing biodiversity and protecting endangered species, changes in climate may threaten and diminish their value.

Several types of species have been identified as particularly vulnerable to climate change, including rare or threatened species, migratory species (species that rely on appropriate habitat throughout their range), species that disperse slowly or over very short distances, and some species in alpine and coastal communities (see ch. 2). Table 5-4 summarizes the kinds of species and ecosystems most at risk from climate change. Endangered species may be especially at risk because they are already significantly stressed and many require a narrow band of environmental conditions for survival. The Endangered Species Act (P.L. 93-205) is currently the primary mechanism for protecting these species. Federally protected natural areas may have difficulty fulfilling their roles of endangered species protection in the future under climate change. As a result, pressures to protect species may increasingly shift to Federal lands not currently protected as natural areas and lands under other ownership, if those lands are suitable for species habitat. Box 5-D **highlights** implications for this act under climate change.

Diminished Ability to Provide Other Services

Species shifts that occur in a changing climate will likely affect wildlife-related recreation in existing natural areas. Many waterfowl habitats already require intensive management to provide for recreational hunting. Natural shifts in waterfowl migration patterns pose problems for wildlife management in some States.[18] Species valued for hunting that move out of protected preserves will decrease the population of game available in the preserve. On the other hand, rare or endangered wildlife that moves out of protected natural areas and into private or multiple-use lands may be more susceptible to hunting and poaching, making their survival more tenuous. Consequently, opportunities for watching wildlife, photography, and nature study could be diminished in many protected natural areas. One assessment of future recreation supply and demand indicates that, for many reasons, wildlife-related recreation may be in the shortest supply relative to demand of all outdoor recreation by the middle of the next century (131). Climate change is likely to compound this problem if it makes wildlife more susceptible to decline.

Adaptability

Whether a natural area can "adapt," that is, persist and thrive, under climate change, depends somewhat on what species live within its boundaries, but also on the management efforts that help or inhibit adaptation. Climate-induced changes in species composition, pest outbreaks, and the frequency and intensity of fire and drought will complicate the management of protected natural areas. The challenge for managers will be to conserve the processes and resources that characterize a natural area given that the boundaries of

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[18] M. Bean, Senior Attorney, Environmental Defense Fund, personal communication, March 23, 1993.

Table 5-4-Species and Ecosystem Types Most at Risk from Climate Change

Ecosystem, species, or community type	Risk factor
Ecosystem or region type	
Arctic communities	Likely to warm faster; many species in the high arctic depend on food chains based on sea ice, which could be lost if sea ice melts.
Montane and alpine communities	Small, isolated habitat; no migration path; sensitive to temperature and precipitation changes.
Coastal communities	Vulnerable to sea level rise; sensitive to increased salinity.
Wetlands in arid and semi-arid environments	Isolated, small: sensitive to precipitation changes.
Species or community type	
Geographically localized species (refugia) (e.g., the American burying beetle, found in coastal areas of Massachusetts)	Isolated population--climate change could make habitat unsuitable for the entire population.
Populations at the edge of their range (e.g., sugar maple refugia in the Caddo Canyons of Oklahoma)	May be most sensitive to shifts in the climate regime; will be first to experience unsuitable climate regime (some peripheral populations could expand if climate conditions become more favorable).
Species dependent on timing of snow and/or ice melt	Availability of water at specific times is crucial for successful breeding; earlier melt means less water is available during summer months.
Rare or endangered species	Often localized and isolated populations; vulnerable to any habitat changes; vulnerable to cumulative threats.
Migratory species	Dependent on appropriate habitat throughout their entire migratory ranges.
Genetically impoverished species	Less able to adapt to environmental changes through natural selection.
Poorly dispersing species (e.g., freshwater mussels)	Migrate slowly.

SOURCES: J.A. McNeely, "Climate Change and Biological Diversity: Policy Implications," in: *Landscape-Ecological Impact of Climatic Change, Boer,* Matthias, M. Rudolf S. de Groot (eds.) (Amsterdam, Netherlands: IOS Press, 1990), pp. 406429; R.L. Peters and J.D.S. Darling, "The Greenhouse Effect and Nature Reserves," *Bioscience, vol.* 35, No. 11, December 1985, pp. 707-717.

the protected lands are freed but that species may move through, over, or around them. In addition, as species shift, managers will have to decide what changes should be assisted (e.g., finding suitable habitat for certain species) and what should be left to "natural processes. " Climate change may bring into question the general management philosophies of different management regimes (see box 5-A). To incorporate long-term climate change considerations into overall land-management decisions, the following areas need to be examined: 1) the management of natural and human-caused disturbances, 2) Federal land-acquisition and land-use incentive programs, and 3) the information base that guides management decisions.

Disturbance-hfanagefnent Challenges

Pests, nonindigenous species, fire, and human use pose the greatest disturbance threat to ecosystems under climate change.

Pests and nonindigenous (exotic) species. It is likely that climate change could accelerate the spread of undesirable plants, insects, and pathogens (128). Usually, indigenous species are better adapted to the environment and compete successfully with introduced species, thus, most undesirable exotic species do not become established. However, under climate change, many nonindigenous species considered undesirable are predicted to be favored (see ch. 2) (72). Thus, Opportunistic weedy species, pests, and disease-carrying organisms may replace or infect indigenous species (95, 128, 161).

Invasion of nonindigenous species can have profound effects on biological diversity. For example, in the western United States, bunch grasses, sagebrush, and other species dominated the arid region of southern Idaho before human settlement. Now, cheatgrass, an annual grass introduced from Europe, dominates the region (28). Cheatgrass is valuable as forage in the spring, but in the summer, it becomes flammable and worthless as forage. The Fish and Wildlife Service estimates that nonindigenous species have contributed to the decline of roughly 30 percent of the listed endangered species in the United States (9). Increased invasions under climate change pose a significant problem to natural area management.

National Parks emphasize the maintenance of historically, naturally occurring species within their boundaries. The current policy explicitly states that species that move onto the park as a result of direct or indirect human activity are not considered "native" (i.e., indigenous to the park) and that "non-native species will not be allowed to displace native species if this displacement can be prevented by management" (153). Under a strict application of this policy, trees or other organisms that migrate into a park in response to climate change would be considered ''nonnative.'' Such a policy might be desirable today to stem the spread of weedy and undesirable species, but a three-pronged problem could emerge under climate change: 1) control of undesirable nonnative species may become more costly in the future if these species are favored under climate change, 2) policies may prevent "naturally" migrating species from moving into parks, and 3) efforts to protect existing or historical species composition, if not impossible, may become more difficult and costly. In short, what is considered "exotic," or nonnative, today may become ''native" under climate change. For the case of migration, it may be useful to distinguish exotic but nationally indigenous neighbors from exotic and nationally nonindigenous neighbors.

The Fish and Wildlife Service policy on nonindigenous species is not as clear as the National Park Service policy. Clarification of this policy could aid future management decisions under climate change. Although FWS policy maintains that the National Wildlife Refuge System exists for the "protection and management of plants and animals native to the United States," this policy makes no regional distinctions among "native" species and is heavily qualified elsewhere in other FWS policies: "[t]he attainment of natural diversity is not an overriding objective of refuge management, but it should be an underlying consideration for all. . . management activities" (143). This tension reflects the fact that many refuges are actively and intensively manipulated to attain certain objectives that may or may not conflict with efforts to protect "native" species.[19] Other ''nonnative" species, including pests, not purposefully introduced or already present on refuge lands are controlled when they interfere with refuge objectives (128). Thus, despite a policy to consider natural diversity on refuge lands and a policy to protect ''native,' or indigenous species, some tolerance for "nonnative" species is allowed and sometimes encouraged.

[19] For example, "nonnative" grasses may be planted in refuges ''when native grassland management will not achieve the refuge waterfowl production objective" (144).

The policy regarding nonindigenous species is also unclear for Wilderness Areas.[20] Given the general 'hands-off" management philosophy for most Wilderness Areas, increased invasions and infestations of nonindigenous species under climate change could be considered consistent with wilderness-management objectives. Yet, significant change caused by such invasions could also be interpreted as diminishing the wilderness character and wilderness values of the area. Noxious farm weeds (i.e., pests that damage agriculture plants), which are defined by State agencies and may or may not be indigenous to the area, can be controlled on Forest Service Wilderness when they threaten lands surrounding the wilderness. Nonindigenous wildlife species already established on Bureau of Land Management Wilderness Areas ''may continue where they enhance the wilderness character of a particular wilderness''[21]; however, management of nonindigenous plant species has not been explicitly addressed (139). Forest Service Wilderness Area policy does not permit control of "pests" except in cases where resources on adjacent lands are threatened or if the pest is nonnative and contributes to a significant loss of the wilderness resource (129). Only control measures that have the least adverse impact on the wilderness area can be taken.

Fire Management. Tree-ring studies in Sequoia and Kings Canyon National Parks in California have shown that regional intense and frequent fries have been associated with drought events in the past (116). Climate change could increase the frequency and intensity of fires for natural areas if droughts become more frequent and if forest dieback accelerates and/or spreads.[22] Several problems could emerge. Pressures to suppress all fires in natural areas could intensify (despite a change in the natural fire regime), and costs of fire control could consequently increase.[23] Removal of fuel buildup may become more important for catastrophic-fire prevention, but as areas become drier and drier, it becomes dangerous to bring heavy machinery into dry forested areas to remove fuel because sparks and motors may easily ignite frees. In addition, some fire-control measures could damage natural area values. Finally, efforts to maintain the 'natural' function of fire in ecosystem development in protected natural areas may be severely hampered.

Fires have been recognized as an important natural process that shapes an ecosystem as its components evolve over time (67, 177). In recent years, lightning-ignited frees have been allowed to bum naturally in National Parks, if life or property are not seriously threatened. This natural fire policy was subject to considerable scrutiny after the 1988 fires in Yellowstone National Park (see box 5-I). Dry, hot weather conditions combined with years of fire suppression and excessive fuel buildup caused over 740,000 acres of the park to bum (167). A National Fire Management Policy Review Team was established by the Secretaries of Agriculture and the Interior to review fire policies for parks and other federally protected natural areas and to make recommendations for fire management in the future. The team's report reaffirmed the positive role of fire in ecological processes for natural areas, but urged that the policies be clarifled and strength-

m However, management policies for Wilderness Areas under the jurisdiction of the National Park Service generally follow management policies for NPS natural areas. Some of these policies maybe more strict than wilderness management policies in other Federal agencies,

21 It is not clear how the determination is made that a species "enhances the wilderness character' of a Wilderness Area.

22 An example of the combined impacts of drought and disease spread is evident in the Blue Mountains of Oregon. The parched conditions in the West bave left drought-intolerant Douglas-firs vulnerable to disease spread. Currently, over 50 percent of many forests and Wilderness Areas in these mountains arc dead or dying (133). The area has been described as a tinderbox for wildfires (see box 6-E for *more detail).*

23 To implement the Fire Policy Review Team's recommendations and to effectively carry out a comprehensive, safe fire-management program, both the Forest Service and the Park Service have stated that substantial increases in funds and personnel are needed (165).

Box 5-I-The Yellowstone Fires of 1966: Harbinger of Climate Change and Fire Management Conflicts

The Yellowstone fires of 1966 illustrate how changes in climate may pose probiems for natural area management. After nearly a century of fire-suppression policies on Federal lands, scientists and managers recognized fire as an important part of ecosystem health and function. Recent policies for Federal natural areas aim to reintroduce the natural role of fire by allowing naturally ignited (and some human-ignited) fires to burn under certain conditions, as long as life and property are not threatened. Although this policy had been relatively uncontroversial since the early 1970s, the fires in Yellowstone in 1966, and others like them, quickly brought such seemingly sound policies into question. Climate changes that result in fire-favorable conditions could move the natural “fire regime” toward more frequent and/or intense fires. The resulting implications for natural areas are twofold. First, efforts to maintain the natural role of fires could be hampered. Second, increased risks to life and property caused by fire could require more costly fire-control and -prevention measures.

Fire management in National Parks has evolved over the past century. The first experiments allowing lightning-caused fires to burn (prescribed natural fires) occurred in 1972, and by 1976, over 75 percent of Yellowstone was designated a natural fire zone. For 16 years, 235 fires were allowed to burn. The largest fire burned 7,400 acres (3,000 hectares)[1], but the majority burned an acre or less. Because there was no loss of life, property, or endangered species, the existing fire policy was considered a successful, tried, and tested management practice by 1966.

The 1960s were marked by drought conditions for most of the Rocky Mountain region. However, peculiar weather patterns over Yellowstone brought drier winters and wetter summers, which stemmed some drought impacts. The spring of 1966 was beginning to look like the beginning of another wet summer. Although June was a time of moderate drought, in July, the National Weather Service forecast normal precipitation Ievels for the rest of the summer. However, by July 15, managers knew that the fire danger was extremely high; the decision was made on July 21 to suppress all fires.

The dangerous fire situation was not a result of summer drying alone. Six dry, cold fronts that pushed through the area created winds that helped the fires spread quickly. In addition, the fires did not die down at night, when humidity usually slows fire movement.

When the fires finally died in September, over 1.4 million acres of the Yellowstone ecosystem region were affected by fire-representing 10 percent of the entire ecosystem and 36 percent of Yellowstone National Park itself (67). Over 9,500 fire fighters were in action at peak fighting time, and the cost of suppression efforts totaled over $120 million. Even so, many speculate that the suppression effort did not significantly reduce the total area burned. instead, 0.25 inches (6 mm) of precipitation on September 11 was largely responsible for ending the fires-not human techniques. Wildlife losses were minimal considering the extent of the fires: less than 1 percent of the summer elk population was lost, and nine bison, two moose, and four grizzly bears died. Native vegetation has quickly reoccupied burned areas, and the diversity of plants and animals in the area is just as high as it was before the fires. Yellowstone visitor rates have not been affected by the fires-the numbers of visitors in 1969 and 1990 were higher than ever before and reached 3 million for the first time in 1992.

Because there were no large fires under the natural fire-management policy before 1966, managers and the public were not prepared for a grand-scale fire. Public perception of the fires as destructive to park resources and local economies, and the possibility that the fires could spread to inhabited areas evoked harsh criticism of fire-management policies of the National Park Service and other Federal agencies. To address these criticisms, the Secretaries of Agriculture and the Interior established a Fire Management Policy Review Team to “determine the appropriate fire policies for national parks and wildernesses which address the concerns expressed by citizens and public officials about the management of fires on these lands as a result of the Yellowstone fire situation” (136).

1 To convert acres to hectares, multiply by 0.405.

The review team found that the basic approach of allowing natural fires to play a role in ecological processes was sound, but that policies regarding the treatment of wildfires needed to be refined. As a result, the agencies have amended their policies to clarify procedures, improve coordination, and tighten criteria for using and managing prescribed fires. For example, prescribed fires in Forest Service Wilderness Areas must be contained within a specified perimeter, and resources must be available at all times to keep the fire in the prescribed area (1 73). To be allowed to burn, fires in the National Parks must meet a set of criteria that include drought and size considerations. When these criteria are not met the fire is to be considered "wild" and must be suppressed (79). However, problems remain in implementing an effective, coordinated prescribed fire program (165). Interpretation of the review team's recommendations has not been uniform across land-management agencies, leading to inconsistencies and revealing a lack of coordination *in* areas with common boundaries (3, 34, 79). Lack of adequate funding, personnel, and equipment as well as internal resistance from some land managers have also been cited as impediments to implementing a more controlled and coordinated prescribed-fire program (40).

If climate change leads to shifts in the natural fire patterns for some regions or leads to weather situations conducive to large fires, it may be more difficult to allow fire to behave as a natural process in natural areas; t here may be more pressure to control the fire regime and suppress large "natural" fires.

SOURCES: The Office of Technology Assessment, 1993; J.D. Varley and P. Schullery, "Reality and Opportunity In the Yellowstone Fires of 19SS," in: *The Greater Yellowstone Ecosystem*, R.B. Keiter and M.S. Boyce (eds.) (New Haven, CT: Yale University Press, 1991).

ened (136).[24] Despite the review team's recommendation that Federal agencies should cooperatively develop prescribed fire programs and contingency plans, there have been problems in achieving a truly coordinated program across agencies (165). Lack of funding, personnel, and equipment, and a resistance to instituting a prescribed fire policy among some agency personnel have also been cited as impediments to implementing an effective, safe, prescribed fire program (34, 40, 165).

Although these policies pertain to both natural and prescribed fires, use of prescribed fires is not encouraged in some National Parks because of the policy to let natural processes govern to the extent possible (67). (However, prescribed fires are more widely used in other National Parks to control unnatural fuel buildup.[25]) Prescribed fires are also not widely used in Wilderness Areas, especially during drought conditions, when fire risks are high.[2G] Ironically, this could be the very time that most ecologically significant fires have occurred in the past. Removing trees to reduce fuel loads is allowed only in emergency situations in some Wilderness Areas. Fire management in protected natural areas presents a dilemma to managers: to minimize fire risk during dry years, many fires are suppressed and few are ignited. Yet, multiple dry years without frees result in greater fuel buildup and very high risks of catastrophic fires.

Human-Use Management. In recent years, reports on the condition of the National Parks have cited overcrowding and damage from visitor use as among the main threats to park resources (17, 154, 158). Because the parks were estab-

~ NPS and all agencies with jurisdiction over Wilderness Areas (including FWS, the Forest Service, and BLM) have revised their policies to allow "prescribed" fires (human or lightning ignited) to burn only under specific conditions as stated in a Fire Management Plan. All fires that do not conform to the specified conditions of the plan (e.g., they become more intense or spread outside the specified fire perimeter) are considered "wildfires" and are to be suppressed (79, 155, 173).

25 D. Parsons, Research Scientist, National Park Service, Sequoia and Kings Canyon National Parks, personal communication, March-April 1993.

26 J.T. Williams, Branch Chief, Fire Use and Fuels, Fire and Aviation Management, USDA Forest Service, personal communication, March 22, 1993.

Lakes, ponds, rivers, and wetlands provide excellent opportunities for canoeing and other aquatic sports. This salt marsh along the Potomac River harbors crabs, osprey, blue herons, and bald eagles, and serves as a nursery for young fish.

lished by the Organic Act to allow visitor use, pressure to keep them open to all visitors is high despite the resource damage caused by overuse. Although NPS maintains a policy of restricting use if necessary to "prevent derogation of the values and purposes for which the park was established," restricting visitor use remains controversial (153).

Under the Wildlife Refuge Administration Act (P.L. 9044) and the Refuge Recreation Act (P.L. 87-714), recreational uses such as hunting, fishing, and boating are allowed on the National Wildlife Refuges if the use is "compatible" with the primary refuge objectives. A use is compatible if it does not materially interfere with or detract from the purposes for which the refuge was established (6).[27] However, compatibility judgments are subjective. A 1989 General Accounting Office (GAO) survey of refuge managers showed that about one-third of all uses considered "harmful' by refuge managers were permitted as a result of political or community pressures (163). Several other harmful activities occurring on wildlife refuges are not under FWS authority (e.g., military air and ground exercises) or are included as one of the purposes for which the refuge was designated (e.g., oil drilling), thus limiting the ability of refuge managers to protect refuge values. Since the GAO study, the Fish and Wildlife Service has implemented several actions to correct public-use problems including enhanced coordination with other agencies and the alteration of use patterns on many refuges."

Because of the mandate to maintain the pristine condition of Wilderness Areas, these areas carry the most restrictions with regard to human use. The number of visitors is limited and generally only foot and horse travel is allowed. Wilderness areas still face threats from human use in the form of eroded trails, litter, and trampled vegetation (l64). As demands for wilderness-related recreation increase, these trends are likely to worsen (131).

Acquisition Policies

Climate change may also bring into question current land-acquisition policies for federally protected natural areas. Future land-acquisition decisions could consider the implications of climate change. For example, will the area persist under climate change, and will it buffer existing natural areas or serve as abridge to other areas for migrating plants and animals? Should corridors (habitat that connects existing protected natural areas) be encouraged? Should the edge of species ranges be acquired and protected? Should habitats such as coastal wetlands be acquired if they are likely to become submerged as sea level rises? Should protected areas be established along elevational and latitudinal gradients to provide for migration?

Federal Acquisition Programs. The Federal Government continues to acquire substantial amounts of land for its various protected natural

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27 However, some uses that frequently interfere with other refuge purposes, such as cattle grazing and oil drilling, are authorized by law when the refuge is established.

28 Robert Schallenberger, Chief, Division of Refuges, U.S. Fish and Wildlife Service, personal communication, March 1993.

Box 5-J-Possible Funding Sources for Conservation Programs

User f-These fees are politically attractive because, ideally, those who value the resource the most pay for its protection. However, there is often strong opposition to such fees, especially for use of Federal lands. Also, in the case of wildlife-related activities, it is often difficult to identify the "user."

- *Recreation* fees(for Federal land use)--Many federally protected natural areas and Federal multiple-use lands charge fees for recreation: entrance fees, camping fees, concessioner fees, and seasonal and annual passes for National Parks. Voluntary donations are also accepted. However, some contend that the fees are either too low or do not feed directly into better management of the natural area (101). Some National Parks (e.g., Great Smoky Mountains National Park) have legislation that prohibits entrance fees.
- Excise *taxes* modeled on Pittman-Robertson and Dingell-Johnson programs-These taxes establish funds to protect game and fish habitat, respectively, by imposing a tax on hunting and fishing equipment. Possible additional targets for excise taxes include fuel for motorized vehicles (off-road vehicles and lawn mowers) and back-country recreational equipment.

Mitigation fees-These fees have great potential as a funding source. The idea is to tax or charge a fee on items or activities that are harmful to wildlife but that are perceived as necessary to society. The funds can then be targeted for protecting wildlife habitat through acquisition or matching grants and for obtaining water for natural **areas.**

- *Land and Water Conservation Fund-This* fund is already in place and is the most widely used fund for protection of wildlife and endangered species habitat. A certain percentage of revenues from oil drilling and exploration on the Outer Continental Shelf (OCS) is placed in the fund for land acquisition and species protection. OCS activities provide 85 percent of LWCF funding. However, appropriated amounts have been about one-third of the authorized amount in recent years.
- Fees on new development of *nonrenewable resources (e.g.,* oil and gas, minerals, and geothermal energy)-Eleven States have such programs in place.
- *Development and impactt fees--For* example, developers who want to build insensitive habitat could be made to contribute to a fund used to protect wildlife habitat elsewhere. Similarly, donation to a conservation fund could be required for road-construction activities.
- *Mandatory land* dedication--California cities can require developers to dedicate 3 to 5 acres (1.2 to 2.0 hectares)[1] of open space for every 1,000 people the development will accommodate. A similar program can be established at the Federal level for new development that uses Federal money. At the Federal level, wetland mitigation is required for development activities that destroy wetlands under Section 404 of the Clean Water Act (P.L. 92-500) (see ch. 4 and vol. 1, box 5-C).

Voluntary donations-These can be a good source of revenue, especially when the donator benefits indirectly from the donation through, say, enhanced business activity. However, voluntary funds are unpredictable and subject to economic fluctuations and competition with other voluntary programs. Wildlife advocates stress that voluntary donations should be used to supplement other funding sources, but should not be the sole funding source (168).

- *Recreation-enhancement taxes-Manufacturers* of recreation equipment may pay voluntarily to a fund that benefits the activity for which equipment is used.
- Income tax check-offs-Typically, there is a box that can be checked on income tax forms to dedicate money for conservation efforts. Many States have successfully initiated this type of checkoff, but it appears that competition with other checkoff boxes has limited its success.
- *Land or land easement donations-Tax* deductions or property tax relief may encourage donation of land or easements under which property is protected.

1 To **convert** acres to **hectares, multiply by 0.405.**

(Continued on next page)

Box 5-J-Possible Funding Sources for Conservation Programs-(Continued)

General funds-Congress can appropriate funds for wildlife and natural area conservation. However, appropriations are also subject to short-term economic fluctuations and competition with other programs.

- The Fish *and* Wildlife Conservation *Act of* 1980 funds--This act was established to provide up to $5 million in financial assistance to States for nongame wildlife conservation. However, the act has not appropriated any money since its enactment, even though many States are ready with conservation programs should the funds be made available.
- *Highway-trust-fund appropriations--these* could be targeted for natural area protection.
- *Partnerships and incentives program--The U.S.* Department of Agriculture's Forest Service has initiated several partnership and incentives programs aimed at encouraging private and State conservation and stewardship efforts through matching-grant and other Federal assistance programs (see ch. 6).

SOURCES: President's Commission on Americans Outdoors, *Americans Outdoors: The Legacy, The Challenge* ('Washington, DC: Island Press, 19S7); S.D. Vickerman, "State Wildlife Protection Efforts: The Nongame Programs, in: "*In Defense of Wildlife: Preserving Communities and Corridors* (Washington, DC: Defenders of Wildlife, 19S9), pp. S7-96.

area systems. Land can be *acquired* for inclusion in a Federal natural area system in a variety of ways: through purchase, condemnation, donation, exchange with private landowners, or transfer from another Federal agency. Direct purchase (where the cost is paid) is not the most common method for acquiring lands. For example, FWS and NPS have each acquired only 2 percent of their land base since 1965 through direct land purchases (124). Land exchanges, easements, and purchase of partial interests are more common. (Box 5-J describes some possible funding mechanisms for conservation projects.)

Funds for most acquisitions come from the Land and Water Conservation Fund (LWCF), though additional funds from the Migratory Bird Conservation Fund and the North American **Wetlands** Conservation Fund are available to the Fish and Wildlife Service. Since the LWCF was established in 1964, the Departments of Interior and Agriculture have spent $3.6 billion for land acquisition and have given $3.2 billion to the States for their conservation programs.[29] Between 4 and 5 million acres of private land have been acquired by the Federal Government through the LWCF over the past 25 years (86). Although $900 million has been authorized for the LWCF each year since 1978, actual appropriations have averaged less than one-third of the total authorized amount in recent years (see fig. 5-7) (86).

Each land-management agency has different procedures and criteria for acquiring land. NPS does not have an overall, long-term acquisition plan. It determines acquisitions on a case-by-case basis considering the following criteria: 1) degree of national significance, 2) degree of suitability and feasibility, and 3) appropriateness of NPS protection over State or private protection. Generally, preference is given to ecosystem types that are not already represented in the system; are less stressed, damaged, or fragmented; and are of sufficient size and shape to "ensure long-term protection of resources and to accommodate public use" (153). Congress must also authorize any new additions to the National Park System.

Acquisitions for the National Wildlife Refuge System follow the Land Acquisition Priority System (LAPS), a systematic priority-setting scheme developed by FWS. Under this system, areas for acquisition are targeted if they contain endangered species, fishery resources, migratory bird habitat, significant biodiversity, or nationally

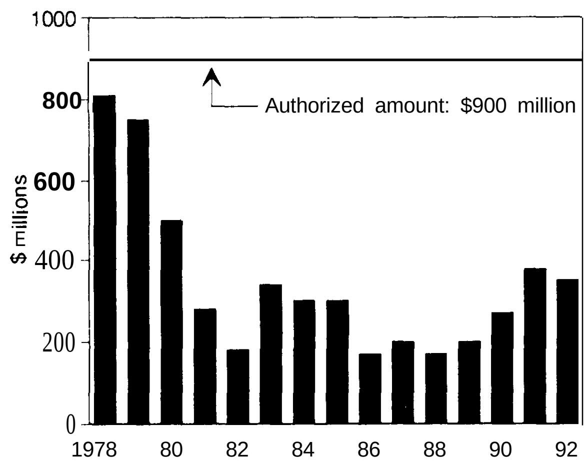
29 Of this total appropriated amount, up to 60 percent can be made available as matching funds to the States for private land acquisition.

significant wetlands. Acquisitions for each target area are authorized by separate congressional mandates such as the Endangered Species Act and the Emergency Wetlands Resources Act (P.L. 99-645) (150). Criteria for target areas include whether the size of the land will meet immediate habitat requirements and whether the area is accessible to the public; however, fragmentation and long-term needs are not primary considerations.

Additions to the National Wilderness Preservation System (NWPS) usually include lands already under Federal ownership that have been recommended by the major land-management agencies. Thus, additions to the NWPS usually require a change in management status rather than ownership. Like additions to the National Park System, new Wilderness Area designations must be approved by congressional legislation. Ideally, the most important criteria for new additions to the NWPS are whether the area: 1) "generally appears to have been affected primarily by the forces of nature; 2) has outstanding opportunities for solitude or a primitive or unconfined type of recreation; 3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and 4) may also contain ecological, geological or other features of. . . value' (P.L. 88-577). Each of the major land-management agencies has been directed to evaluate its lands for additions to the system. However, because of conflicts among resource-use groups and wilderness advocates, many areas are still under consideration and have not yet been designated (102).

Federal Incentive Programs. In addition to Federal acquisition programs, several incentive programs are in place to protect natural areas and to augment the Federal system of natural areas. The Federal Government can use up to 60 percent of the Land and Water Conservation Fund to help States plan, acquire, and develop needed land and water areas. Once a comprehensive plan has been approved, the Federal Government may provide up to 50 percent of the costs of the project.

Figure 5-7-Authorizations and Total Annual Appropriations of Land and Water Conservation Fund



SOURCE: National Research Council, 1993.

Although many of these projects are primarily recreation projects, some do have substantial benefits for wildlife (6).

Through the Federal Aid in Wildlife Restoration Act of 1937 (the Pittman-Robertson Act, P.L. 99-396), Federal financial and technical assistance is provided to the States for acquisition, restoration, and maintenance projects for wildlife habitat or for developing a fish and wildlife resource-management plan. Up to 75 percent of project costs are paid by the Federal Government, and the rest is paid by State matching grants. The Federal portion of the cost is paid primarily through revenues from excise taxes on hunting equipment. As a result, most projects are aimed at benefiting game species. The Federal Aid in Fish Restoration Act of 1950 (the Dingell-Johnson Act, P.L. 100448) is a similar act that provides up to 75 percent of the costs to the States for projects or management plans pertaining to fish through revenues from excise taxes on fishing equipment and related items. In both cases, the Federal money is dispersed to the States with little guidance about how it should be used.

The Fish and Wildlife Conservation Act of 1980 (P.L. 96-366) sought to fill the gaps in the Pittman-Robertson, Dingell-Johnson, and Endangered Species Programs by providing protection through a similar matching-grant program for species that are not game and not endangered. However, the program is funded at the Federal level with direct congressional appropriation (unlike the fish and game acts, which are funded by taxes), and no money has ever been appropriated for this purpose since the law was passed in 1980. Under this program, the Federal Government would provide up to 75 percent of the costs to the States of preparing a comprehensive management plan for all vertebrate species. This law—already on the books--could be funded and amended to encourage an ecosystem-level approach to management by including protection for plant and invertebrate species and by requiring States to prepare ecosystem-management plans before receiving funds.

In addition to these grant and cost-sharing programs, other Federal programs provide easements and other incentives for resource protection. The Environmental Conservation Acreage Reserve Program, which combined the Conservation Reserve Program and the Wetlands Reserve Program in the Food, Agriculture, Conservation, and Trade Act of 1990 (P. L. 101-508), encourages owners to enroll certain wetlands and highly erodible lands in the program in return for easement payments and access to cost-sharing programs. In addition, the "Sodbuster" and "Swampbuster" programs established by the Food Security Act of 1985 (P.L. 99-198) and the Food, Agriculture, Conservation, and Trade Act seek to combat erosion and wetland destruction by withholding Federal benefits if erodible lands are planted or wetlands are converted. (See chs. 4 and 6 for more detail on these programs.) These Federal programs encourage State and private landowners to manage lands in particular ways. The programs could be used to augment the existing Federal system of natural areas while accomplishing their broader environmental goals and without changing landownership patterns.

Research, Inventorying, and Monitoring

There are many gaps in our understanding of ecosystem structure and function. The Ecological Society of America's (ESA's) Sustainable Biosphere Initiative identified five priority areas in need of increased ecological research: 1) ecological causes and consequences of changes in climate, soil, water chemistry, and land-use patterns; 2) 'ecologica1 determinants and consequences of biodiversity and the effects of global and regional change on biological diversity; 3) definition and detection of stress in natural and managed ecosystems; 4) restoration of damaged systems; and 5) management of pests, pathogens, and disease on a sustainable basis (70, 85). (See box 5-K.)

Our ability to detect and verify resource changes and climate impacts is insufficient. Nevertheless, there are some notable programs (highlighted in box 5-L) that are beginning to bridge the information gaps and could serve as building blocks for future programs. These programs include the Environmental Protection Agency's (EPA's) Environmental Monitoring and Assessment Program, FWS'S Gap Analysis Project, and the National Science Foundation's (NSF's) Long-Term Ecological Research Program.

In early 1993, President Clinton announced the establishment of a National Biological Survey (NBS) in the Department of the Interior.[30] Although the scope and structure of the NBS is still in the formative stages, there are indications that the NBS will consolidate the biological research, inventorying, and monitoring activities for the Department of the Interior into a free-standing,

30 Representative Gerry Studds, D-MA, introduced H.R. 1S45 to establish the National Biological Survey in the Department of the Interior on April 22, 1993. The President's FY 1994 budget requested that $179,445,000 be transferred from the eight DOI bureaus to the NBS. H.R. 2520, appropriations for DOI and related agencies for FY 1994, suggests transferring $163,604,0(X).

Box 5-K—The Sustainable Biosphere Initiative: Articulating an Ecological Research Agenda for Global Change

Responding to the need for definitive scientific priorities in a world of constrained research dollars and a rapidly deteriorating environment, the ecological research community, through the Ecological Society of America, has identified three areas of high-priority research that address fundamental ecological questions as well as concerns about the sustainability of the biosphere: global change, biological diversity, and sustainable ecological systems. The societyhasformalized these priorities in a program called the Sustainable Biosphere initiative (SBI). SBI is a "call to arms" for ecologists as well as a framework for the "acquisition, dissemination, and utilization of ecological knowledge which supports efforts to ensure the sustainability of the biosphere" (70). SBI is envisioned to be broader than a basic research program by contributing to efforts in research, education, and environmental decision making.

Several of the research areas identified by the Office of Technology Assessment (OTA) as important for understanding the nature of climate impacts on natural areas and ecosystems in order to maximize adaptation possibilities (such as restoration ecology and climate-ecosystem interactions) are also identified as high-priority research areas by SBI. The key research topics identified by SBI are listed below (70):

- the ecological causes and consequences of global climate change,
- the effects of global and regional change on biodiversity,
- indicators of ecological responses to stress,
- biological inventory,
- the biology of rare and declining species,
- the restoration of ecological systems,
- the ecology of disease spread,
- the consequences of land and water-use change,
- the causes and consequences of changes in atmospheric, soil, freshwater, or marine chemistry (including changes in carbon dioxide), and
- the development and application of ecological theory to the management of ecological systems.

The Sustainable Biosphere initiative fosters the application of good science to large-scale questions and the use of scientific knowledge to solve critical management issues. An interagency Working Group has been formed to enhance communication and interaction between agencies and to promote decisions that solve critical management issues in away that recognizes the need for sustainable ecological systems.

The Interagency Working Group has identified two interagency demonstration projects, one in south Florida, and one in the Southwestern U. S., focused on the Rio Grande Basin. The vision is to use these projects to demonstrate that several agencies (regulatory, scientific, and management based; Federal, State, and local) plus academia can work together to meet a common objective: sustainability of critical ecological systems.

SOURCES: J. Lubchenco et al., "The Sustainable Biosphere Initiative: An Ecological Research Agenda," *Ecology*, vol. 72, No. 2,1991, pp. 371-412; Office of Technology Assessment 1993.

nonregulatory bureau (5). This change provides an opportunity for the Department to seriously examine its existing and future research needs, improve existing programs, eliminate ineffective ones, and address gaps in research, inventorying, and monitoring that have developed over the years. An examination of existing research programs, as they relate to climate change would contribute to this process by identifying the gaps and strengths of existing research efforts that are important for the long-term management of Federal protected areas and other natural areas.

Research. Although ecological research is one of the overall priorities in the United States Global Change Research Program (USGCRP), relatively little research is being supported that

Box 5-L-Building Blocks for Integrated Information Systems

The U.S. Environmental Protection Agency's (EPA's) Environmental Monitoring and Assessment Program-The Environmental Protection Agency (EPA) launched the Environmental Monitoring and Assessment Program (EMAP) program in 1967. It is aimed at: 1) estimating the current condition of the Nation's ecological resources, 2) monitoring indicators of pollutant exposure and habitat condition, and 3) providing periodic summaries and interpretive reports on ecological status and trends to resource managers and the public (162). The program stemmed from EPA's Science Advisory Board recommendations for a comprehensive program to monitor the status and trends of ecosystems so that environmental problems can be anticipated. This program could be used to help detect and monitor climate-induced changes in the environmental EMAP is meant primarily to provide a "national overview" of ecological status and trends. Because of the large grid size for monitoring, it is not a substitute for intensive, site-specific monitoring that maybe required for actual land management.

The program is organized by resource category: estuaries, Great Lakes, surface waters, wetlands, forests, agroecosystems, and arid ecosystems. The monitoring program for forests is the most developed so far. Several ecological indicators are measured at each monitoring site. *Condition indictators* represent the ecological condition or physical attributes of an organism, population, community, ecosystem, or landscape (e.g., vegetation and species). *Stressor Indicators* can be measured to indicate contact with specific stressors or to quantify natural processes and human-caused events that may affect biota and their habitats (e.g., pollutants). Data are acquired through field surveys, remote sensing (e.g., satellite images and aerial photography), and other monitoring programs. Much of this work is carried out in conjunction with other Federal agencies including the U.S. Department of Agriculture (USDA), the Department of Interior (DOI), the Department of Energy (DOE), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). EMAP also draws on other monitoring initiatives, such as the Forest Health Monitoring Program of the USDA's Forest Service and the U.S. Geological Surveys (USGS's) National Water Quality Assessment Program. Twelve Federal agencies and 19 States are participating in EMAP through imperative agreements.

EMAP activities are not limited to monitoring. Other main components of the program include integration and coordination activities that aim to ensure uniform, high-quality sampling and assessment methods, consistent documentation, and effective information management. Research is under way to help improve EMAP through pilot projects. The entire program, when fully implemented, should cost about $100 million annually.[2]

The U.S. Fish and Wildlife service's Gap Analysis Pro]ect-in 1991, the U.S. Fish and Wildlife Service initiated the Gap Analysis Project (GAP), which was intended to aid in State and Federal wildlife acquisition and protection efforts by identifying areas of high biodiversity that are not under formal protection (107)[3] This "pro-active" strategy aims to stem the accelerated rates of extinctions by allowing managers and planners to protect species-rich areas and unprotected vegetation types before they are threatened and on the brink of extinction.

GAP uses information from The Nature Conservancy (a private, nonprofit conservation organization), the Forest Service, the Bureau of Land Management USGS, State agencies and Heritage Programs,[4] and satellite images to map the potential distribution of plants, vegetation cover types, terrestrial vertebrates, endangered and candidate species, and other indicator species to identify areas of potential species richness and uniqueness

1 It is not clear how this program will contribute to ordrawfromthe inventory and monitoring activities of the new National Biological Survey in the Department of the interior.

2 E.A. Martinko, Director for the Environmental Monitoring and Assessment Program at the Environmental Protection Agency, letter to the Office of Technology Assessment, Oct. 14, 1992.

3 it is possible that GAP activities will become part of the new National Biological Survey.

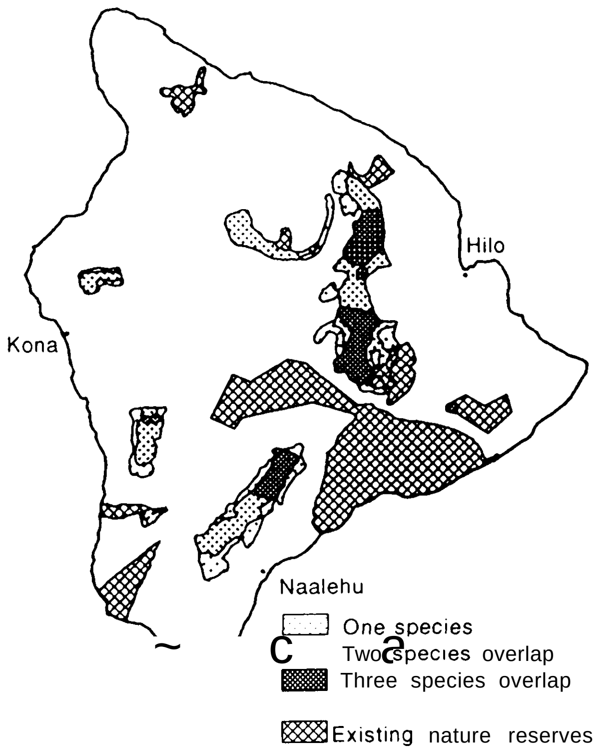
4 State Heritage Programs are cooperative programs between State agencies and The Nature Conservancy for conducting State-wide biological Inventories.

(109). These distributions are overlain with regions under official protection by the State or a Federal agency on a computerized map. The resulting composite reveals "gaps" in protection-areas with high diversity that are not currently protected (see figure at right). This can then help resource managers target protection efforts to maximize the protection of biodiversity.[5]

GAP provides only a general picture of biological resources. Data used for GAP analysis may be incomplete because remote areas were not inventoried, outdated because inventories have not been conducted recently, or too limited because only certain indicator species have been mapped. For these reasons, the vegetation maps produced by GAP maybe best suited as a cost-effective tool for directing more comprehensive biological inventories and for providing a preliminary guide for agency acquisitions, easements, or cooperative agreements. Although localized species may be "missed" with the broad-brush approach, supporters of GAP assert that it could "ensure that the vast majority of species never become endangered."

The National Science Foundation's Long-Term Ecological Research Program-The National science Foundation (NSF) has had a long term research and monitoring program in place since 1980, the Long-Term Ecological Research (LTER) Program. This was the first major program established to provide sustained and systematic support for iong-term studies in ecology (42). Research at each of 17 sites in the United States (and 2 in Antarctica, see figure, next page) combines monitoring activities with basic research focused on five core areas: patterns of primary production, distributions of selected populations, patterns and control of organic-matter accumulation, patterns of other inputs and movements of nutrients through the soil and waters, and patterns and frequency of site disturbance. Because many of these processes require time scales of decades to centuries, LTER projects address spatial and temporal scales normally outside the range of ecological research programs. For this reason, LTER activities may be especially important for climate change-related ecological research.

GAP Analysis Example: Distribution of Endangered Hawaiian Finches in Relation to Existing Nature Reserves on the Island of Hawaii in 1982



SOURCE: National Park Service, 1993.

The LTER program is different from long-term activities in other agencies because it is more rooted in basic research and relies on the peer-review process to ensure continuation of research activities at each site. Because of this focus, the LTER sites were chosen by the quality of research proposals submitted to NSF, not simply by location. However, the existing 19 sites do represent a variety of ecosystem types and degrees of human disturbance (42). Research varies from site to site, but standardized measurements, methods, and software are

[5] S.D. Vickerman, presentation at Managing Western Lands in a Changing Climate, OTA-sponsored workshop held Juiy 1992, National Center for Atmospheric Research, Boulder, CO.

(Continued on next page)

Box 5-L–Building Blocks for Integrated Information Systems-(Continued)

becoming an integral part of the program. Many stations have already produced major scientific findings in watershed disturbance, lake acidification, and climatology.

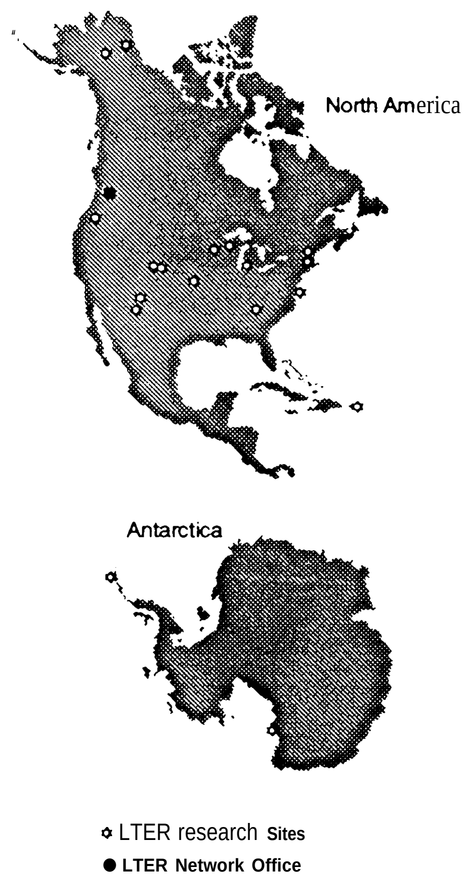
A new plan is being developed for future LTER activity, "LTER 2000," that will create a Global Environmental Research Network. The number of NSF-supported LTER sites will be increased, and links will be made to other sites supported by other Federal agencies to cover key biomes, habitats, and areas lacking adequate coverage.

Because LTER provides sustained, long-term support for basic ecological research, this program could be one appropriate vehicle for expanding and encouraging needed ecological research on climate impacts and responses, as well as for providing long-term baseline information for detecting climate changes in some ecosystems.

The Federal System of Research Natural Areas (RNAs)--This system was established by the U.S. Forest Service in 1927 for conducting nonmanipulative research on a variety of ecosystem types. In the 1930s, the National Park Service (NPS) expanded the idea and began to establish "research reserves" (7). The effort later evolved to include areas for experimental management. A 1974 report of the Federal Committee on Research Natural Areas called **for:**

- the completion of "the existing National System of Natural Areas, with full representation of major ecosystems, to provide sites for studies of naturally functioning systems that can serve as ecological reference points for baseline monitoring, and as controls for experimental research" and
- 'the National System of Ecological Research Areas, to provide sites for manipulative experiments, management testing, and observations of the results of human impact" (57).

The National Science Foundation's Long-Term Ecological Research Network



SOURCE: Long-Term Ecological Research Network 1993.

The idea of a network of Ecological Research Areas that fully represents the range of ecosystems throughout the United States was articulated in a 1975 report by The Nature Conservancy (57). This vision has only partially been fulfilled. The committee has not met since 1979, the integrated system of Ecological Research Areas never materialized, and the existing system of RNAs, a subset of the Ecological Research Areas, is not coordinated and is not representative of major U.S. ecosystems (7, 33). There are now about 340 RNAs constituting roughly 5 million acres (2.1 million hectares)[6] of land under various Federal ownerships, although most RNAs arewith the Forest Service. Because RNAs are under the purview of various agencies and because there is no legislative or institutional mechanism to guide management of the system, the RNA system remains a disjointed collection of lands with no overarching management direction.

If the original vision for RNAs is revived, these areas could become an ideal and important part of natural area conservation under climate change. These areas could function as centers for research on impacts of climate change as well as vehicles for studying natural adaptation. However, because RNAs are typically small (14 to 9,000 acres), they should not be solely relied on for long-term protection (1 74).

The Nature Conservancy's National Natural Heritage Program-The National Natural Heritage Program is an inventory program coordinated by The Nature Conservancy, but implemented by state conservation agencies. The goal of t he program is to maintain a "permanent and dynamic atlas and data bank on the existence, identity, characteristics, numbers, condition, status, location, and distribution oft he elements of natural biological and ecological diversity . . . " (86). Rather than attempting to catalog all biological resources, efforts are targeted toward "the last of the least and the best of the rest": rare, endangered, and vulnerable species (86). Comprehensive (though slightly less detailed) inventories are also conducted for communities and ecosystems within each state.

State participation in the program is entirely voluntary, and except for some private start-up funds, funded primarily by the States. Generally, TNC provides training, standards, procedures, and methods and facilitates coordination with other States while the State conservation agencies are primarily responsible for conducting the actual inventories. Heritage programs have been established in all 50 States. Because the program has been in place and refined for nearly 20 years, because it is national in scope, because it has active State participation, and because the methodologies have been established, this program could serve as a model for a federally based inventory and monitoring effort.

Geographic Information Systems-A Geographic information System (GIS) is a computer-based tool used to manipulate and analyze spatial data such as topography, soils, and vegetation. With a GIS, digitized thematic data can be entered, stored, transformed, measured, combined, retrieved, and displayed. Various databases containing information on flora and fauna topography, soils, geology, and hydrology are standardized and overlaid to display a composite picture. The relative ease in analyzing and displaying these data can allow planners and managers to explore and anticipate the results of various planning decisions at various spatial scales.

GISs have been used to predict the occurrence of populations of certain species, to identify potentially suitable sites for certain species, to estimate the quality and quantity of some habitats, to quantify changes in landscape patterns, and to examine some spatial interrelationships (e.g., distances to various habitats could be computed for different conservation strategies). In addition, because "GIS could be used to identify areas undergoing the most rapid change in which conservation needs might be most crucial," it could be a valuable tool for land management and planning under climate change (86). Although use of GISs is increasing, it varies substantiality among Federal agencies, and the extent of interagency coordination is not clear (86).

The Terrestrial Research Interest Group (TRIG)-The Terrestrial Research interest Group (TRIG) is an ad hoc coordinating committee of Federal agencies and other organizations that conduct terrestrial research. Formation of this informal group was spurred by the perception that research on terrestrial impacts of climate change was not adequately addressed in the Global Change Research Program (GCRP). TRIG seeks to provide a forum for the exchange of information on terrestrial research efforts (including climate change research efforts) and to develop a strategy by which these research efforts can be coordinated (65). The strategy includes identifying relevant geographical regions, management concerns, information needs, and scientific research

6 To convert acres to hectares, multiply by 0.405.

(Continued on next page)

Box 5-L-Building Blocks for Integrated Information Systems-(Continued)

needs and developing plans for efficiently coordinating research efforts and linking them to management and for effectively managing data (65).

Although this group is not a funded entity and its members are volunteers, several efforts are under way to help coordinate research activities across agencies. These efforts include the identification of major issues for terrestrial research and management including issues relating to climate change, and the development of an overall strategy document. Because many of the agencies voluntarily involved in TRIG are also represented on the Committee on Earth and Environmental Sciences in the office of science and Technology Policy, TRIG could help facilitate coordination and collaboration between agencies on both research and management issues. However, further expansion of this group would require some formalization so that members could devote more time to coordinating activities.[7]

The Consortium for International Earth Science Information-The Consortium for International Earth Science Information (CIESIN), a nonprofit corporation, was established in 1969 by FY 1990 appropriations for National Air and Space Administration (NASA) as one of the nine data centers for the Earth Observing System, the satellite component of NASA's Global Climate Change Program. By establishing this corporation, the Federal Government sought to broaden the information-management programs and facilities planned for NASA's Earth Observing System (EOS) and to take the lead in creating an integrated information network accessible to decisionmakers at all levels of government (23). However, in 1993, the Senate Committee on Appropriations deleted the full FY 1994 budget request for CIESIN (CIESIN received $75 million in FY 1993)[8] citing a lack of program focus and duplication of effort with the National Science Foundation.

As a part of its missbnio CIESIN was directed to investigate ways to improve data utilization and management for global change. This effort encompassed several functions: 1) develop and maintain the Socio-Economic Data Applications Center for EOS, 2) foster research on the human dimensions of global change, 3) link existing environmental and global change data centers, 4) serve as an international gateway to scientists, educators, and policy makers, 5) conduct regional cause-and-effect studies of global change, and 6) provide data to other international programs and research efforts. Many of these plans were never implemented.

The Terrestrial Ecosystems Regional Research and Analysis Laboratory (TERRA)--TERRA is an interagency research laboratory formed in 1992 under a Memorandum of Understanding (MOU) agreement between the USDA's Agricultural Research Service, Soil Conservation Service, and Forest Service and the US. Geological Survey in the Department of the Interior. As a part of the global change research activities in these agencies, TERRA is organized to "provide a mechanism for strengthening the linkages between terrestrial ecosystem, atmospheric, and human process components of large-scale ecosystem models" (1 17). The objective of the Laboratory is to provide scientific information in support of national and regional decisionmaking that cuts across scientific disciplines and conventional agency responsibilities; TERRA hopes to characterize the interactions between land use, ecological resources, and land management through the development and analysis of regional models (39). It is hoped that these models will ultimately be able to "test" the consequences of various policies and management decisions affecting natural resources by predicting changes in the distribution and nature of terrestrial ecosystems and developing quantitative methods of assessing ecosystem sustainability under various climate change and land-use-change scenarios. To facilitate information transfer to land managers, TERRA envisions creating a "neutral" facility where scientists, managers, and other stake holders can work with the models to help address regional issues and problems.

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7 J.A. Kelmelis, U.S. Geological Survey, letter to the Office of Technology Assessment Sept. 14, 1992.

8 J.R. Lousma, president and CEO of CIESIN, letter to the Office of Technology Assessment Oct. 8,1992.

SOURCE: Office of Technology Assessment, 1S83.

addresses the uncertainties surrounding the impacts of climate change on ecosystems (see ch. 3). Funding for climate change research within DOI has not been well-supported. In FY 1993, NPS was the only DOI agency to request any increase in USGCRP funding (from $2.6 million to $3.7 million between FY 1992 and FY 1993) (25, 26). DOI was the only participating department that requested a decrease in USGCRP funding in FY 1993 and FY 1994 (25, 26).

Much remains to be discovered about how and to what degree climate factors influence wildlife and plant species, how wildlife interactions enhance or inhibit their ability to adapt, how various changes in vegetation and landscape affect species populations, or what makes a species sensitive to climate change. More generally, little is known about how to facilitate adaptation through either reserve or corridor design, although educated guesses can be made. Transplantation and restoration ecology may become important for saving and protecting more species in a changing climate. However, this discipline is relatively new. Some techniques are not well-developed and others are not widely known (see boxes 5-M and 4-A). The National Research Council (85), the Council on Environmental Quality (30) and the Ecological Society of America (70) have all called for increased efforts in ecological research, especially on larger spatial and temporal scales. One of the functions of the NBS might be to implement research on a large, ecosystem basis (5).

Research for the National Park System is conducted in each individual park unit, through the 10 regional offices, and through some 23 Cooperative Park Study Units with various universities. However, no research is systematically conducted throughout NPS (83). In addition, it is not clear that the existing research efforts are adequate for meeting current management needs, much less management needs for the future. The National Park Service's component of the USGCRP (NPSGCRP)[31] seeks to "provide predictive and holistic understanding of the effects of global change on species populations, ecological communities, watershed processes and landscape dynamics through the coordinated use of parks and benchmark research sites within large [biogeographic areas]" (22). Research activities are centered around the biogeographic area (BGA) concept developed by Unesco's[32] Man and the Biosphere Program (MAB) (see box 5-F), and most NPS research activities for global change take place in U.S. MAB Biosphere Reserves. Although this effort is innovative because it is one of the few USGCRP programs to take a regional approach to climate change research, its scope remains relatively limited, and the program has proceeded more slowly than planned. In addition, scientific research beyond the scope needed for short-term, site-specific management does not receive much support from NPS (83). ''The NPS science program is unnecessarily fragmented and lacks a coherent sense of direction, purpose, and unity," according to a recent study (83).

Most research for the Fish and Wildlife Service aims to aid management efforts and objectives at each refuge. Consequently, "research on systems and species most susceptible to consequences of global climate change is lacking" (66). Research activities at the Fish and Wildlife Service are conducted through 13 national research centers and 89 field stations. The Cooperative Research Program of FWS facilitates cooperative research between FWS, State wildlife agencies, and about 41 universities. Climate change research efforts take place under the FWS Global Change Research Program (FWSGCRP), which seeks to establish a reference base to clearly demonstrate and assess the extent, magnitude, and rate of ecological impacts of global change and to assess the significance of global climate change on FWS resources, especially coastal ecosystems,

31 This program, along with other NPS research activities, is slated to become part of the National Biological Survey.

32 United Nations Educational, Scientific, and Cultural Organization.

Box 5= M-Restoration Ecology: Giving Nature a Helping Hand Under Climate Change

Changes in climate will likely alter the balance of plants and animals that now characterizes natural areas, and could be accompanied by any number of changes in the physical environment including more erosion, flooding or drying, and more frequent or more intense fires. The impacts of climate change will pose a dilemma for managers of natural areas, who must balance the conflicting needs of protecting a specific set of resources, such as endangered species or migratory waterfowl habitat, with the goal of allowing natural ecological processes to proceed (see box 5-B). In some areas, managers may decide that the need to maintain a specific habitat may call for active efforts to protect the plants and animals already in place and to restore habitat that is damaged. In other cases, habitat that has already been damaged by pollution, road building, water diversions, erosion, timbering and grazing, overuse by visitors, and fragmentation (see box 5-E) may now contain the most favorable climate conditions for some species or communities; managers may attempt to add such sites to the boundaries of natural areas and restore them to increase the chances that a given community will survive. In both cases, restoration will be a key part of the management strategy.

Ecological restoration is the attempt to fully restore ecosystems by recreating the entire community of organisms that originally inhabited them. It is different from habitat creation, reclamation, and rehabilitation-each of which can involve manipulation of a small set of species. Restoration involves recreating both the form and the function of a natural ecosystem that is integrated with t he landscape in which it occurs. Restoration varies from site to site, but generally involves two major steps: site preparation to restore desired physical, chemical and water conditions, and biological manipulation including the reintroduction of absent native plant and animal species To begin with, the site is prepared by clearing unwanted vegetation (nonindigenous species), removing contamination, adding topsoil if necessary, and, possibly, grading to create a varied topography. Vegetation is planted, either with seeds from nearby sources of native species or by transplantation of plants from another site. In some cases, measures to restore vegetation maybe more passive--a prepared site maybe allowed to reseed naturally from the surrounding areas or from seed that has remained dormant on-site. However, natural regeneration may be difficult in areas where native species are no longer prevalent or where invasive nonindigenous species are likely to take root quickly. In many cases, animals are allowed to migrate into the area of their own accord, under the assumption that once native vegetation is reestablished, animals will follow. In the case of endangered species, however, managers may devote considerable effort to rearing the species off-site and reintroducing them into the restored habitat.

Early efforts to go beyond simple reclamation and reforestation in attempts to restore full ecosystems were pioneered by ecologists at the University of Wisconsin Arboretum in the 1930s. Researchers there began exploring techniques for restoring the full array of species and functions to prairies and forests that had been cleared for agricultural use. Long-term research on the plots established there continues to yield new information on restoration techniques. Since then, restoration has been applied with varying degrees of frequency and success on other ecosystem types ranging from savanna and shrubland to coastal salt marshes, freshwater wetlands, and rivers and lakes.

One impetus for the development of restoration techniques has been an increasing demand by the Federal Government. Restoration is called for in three separate contexts--regulation, planning, and management. Restoration has entered the regulatory arena through the permit requirements of Section 404 of the Clean Water Act (P.L. 92-500), in which restoration of wetlands can be demanded to compensate for activities that destroy wetlands (see ch. 4), as well as through the requirements covering reclamation of surface mines. Restoration may be part of the planning and construction of federally supported projects as required by the National Environmental Protection Act (NEPA; P.L. 91-190), under which potential damages to the environment and alternatives for mitigating those harms must be evaluated. Finally, restoration is part of ongoing management efforts of many Federal natural areas to combat problems such as overuse by visitors and to protect and restore habitat for endangered species.

An Example of Ongoing Federal Restoration Efforts-More than 3,000 species of wildlife and fish live on Bureau of Land Management (BLM) lands, including 216 federally listed threatened and endangered species and 1,200 candidate plant and animal species BLM manages more fish and wildlife habitat than any other organization. These highly diverse habitats encompass deserts, rangelands, mountains, forests, and tundra.

In 1988, BLM launched an action-oriented program aimed at the more efficient management of the fish and wildlife resources on public lands. The program, Fish and Wildlife 2000, seeks to "ensure optimum populations and natural abundance and diversity of wildlife resources on public lands by restoring, maintaining, and enhancing habitat conditions." A related BLM effort, the Riparian-Wetland Initiative for the 1990's, which was launched in 1991, focuses on restoration and maintenance projects for riparian areas and wetlands with the goal of having over 75 percent of these areas in functioning order by 1997 (138). BLM has utilized a variety of outreach and cooperative programs with States and private citizens to achieve its goals in habitat restoration and improvement efforts. This collaborative approach with partners is enabling BLM to stretch Federal funds and accelerate on-the-ground management and restoration efforts.

BLM estimates that the Fish and Wildlife 2000 will require about $90 million per year for 10 years and the Riparian-Wetlands Initiative will require a total of $127 million for full implementation. However, these programs have not obtained the funds or personnel requested to date. The FY 1993 budget for *Fish and Wildlife 2000 is some $36* million, or about one-third of the planned funding level. Despite this, BLM has made substantial progress in several areas. In California, efforts are under way to restore the hydrologic function and improve the habitat quality for the Modoc sucker on a 9-mile (16-km) segment of Cedar Creek. In Montana, 3,800 acres (1,520 hectares)[1] of wetlands are to be created in native prairie to increase nesting habitat for waterfowl. In addition, other vegetation management is planned to create habitat for a variety of other species in this area.

Despite the increasing demand for restoration techniques, restoration ecology is still a young science. Problems encountered in restoration include site selection, survival of transplanted flora and fauna inadequate nutrient supplies for plant growth, and pest invasions (83). Restoring an ecosystem to its former condition requires a detailed understanding of the numerous components and functions that characterize it; for many types of ecosystems, ecological knowledge is incomplete at that level of detail. To date, restoration research has tended to focus primarily on techniques of reestablishing species composition and community structure. The functional values of restored areas, although widely recognized, are seldom evaluated. For example, it has not been shown that restored wetlands maintain regional biodiversity and recreate functional ecosystems (83). Considerable research is needed in many areas of basic ecological interactions as well as further experimentation on a wide array of ecosystems to ensure that the practice of restoration yields predictable and desired results.

Even as restoration techniques are being refined, the potential for climate change raises new challenges. Past restoration efforts have generally sought to recreate self-sustaining ecosystems in their original conditions-the way they were before human actions disturbed them. But as climate changes, the environmental conditions that originally shaped an ecosystem may fundamentally change, so that an ecosystem restored to its original or natural condition may no longer be self-sustaining. Whereas ecologists are trained to think of ecosystems as dynamic and evolving, much of our natural resource legislation focuses on saving a particular resource in a particular place-a freeze-frame in the film of ecosystem evolution. At what point should restorationists take t hat snapshot? To what should an ecosystem be restored if t he climate has changed around it? As species migrate in response to a changing climate, which will be considered the native species, and which will still be considered nonindigenous? What are the implications of introducing new species that maybe more adapted to the new climate conditions? A changing climate will test the boundaries of the Nation's present thinking about species and ecosystems.

1 To convert acres to hectares, multiply by 0.405.

SOURCES: J.L. Berger and L.A. Riggs, *Ecological Restoration and Non-Indigenous* Speck, contractor paper prepared for the Office of Technology Assessment, August 1991; W.R. Jordan, R.L. Peters, and E. E?. Allen, *Ecological Restoration* as a Strategy *for Conserving Biodiversity*, contractor paper prepared for the Office of Technology Assessment, January 19SS; National Research Council, *Restoration of Aquatic* Ecosystems (Washington DC: National Academy of Sciences Press, 1992).

prairie pothole wetlands, and priority fish and wildlife (147). Support for these important research efforts has waned. In FY 1993, $3.1 million was allocated for the FWSGCRP program, representing a 14 percent decrease from FY 1992.

There is no coordinated research program for the Wilderness Preservation System. All research activities for Wilderness Areas are subsumed in the research programs for the agency that administers each area. However, research activities in place in Wilderness Areas may provide useful information to guide future management under climate change (e.g., monitoring forest health or improving understanding of ecosystems). Only one climate change project, Ecological Change in Environmentally Stressed Ecosystems of the Western and Northern United States, has been funded ($1 million) at BLM despite the large acreage it administers (270 million acres). The Forest Service maintains a larger global change research program (FSGCRP) ($22 million). FSGCRP focuses on four research elements: 1) gas and energy exchange between the biosphere and atmosphere; 2) disturbance ecology; 3) ecosystem dynamics; and 4) human activities and natural resource interactions. FSGCRP is conducted through five regional programs, each addressing the four research elements (134). Because funds are limited, activities tend to focus on immediate management concerns and popular or controversial species (66).

Inventorying and Monitoring. Inventorying and monitoring are extremely important for detecting changes in natural areas (97, 126, 166). However, inventory and monitoring efforts for Federal natural areas are inconsistent, uncoordinated, and often incomplete for establishing a baseline assessment of resource status and for monitoring changes over the long term. NPS maintains a policy to inventory and monitor its resources, and most park units have written descriptions of the plants and animals occurring on park lands. However, NPS inventorying and monitoring efforts are extremely varied in scope and quality from unit to unit, and data are not standardized or properly cataloged (83, 115, 177). Monitoring efforts are often directed at "popular" species and undertaken for management considerations, rather than at representative species and for studies of long-term trends (115, 177). Less than 30 percent of all National Parks maintain adequate data for addressing management questions or for making informed management decisions (154). In 1992, NPS started a program to conduct more complete inventories of NPS lands, and this program is likely to continue under the direction of the new National Biological Survey.

The Fish and Wildlife Service has, possibly, the most complete inventory of the animal species that occur on the lands it manages because of its strong biological focus. Most vegetation inventory efforts focus on wetlands through the National Wetlands Inventory Program. Most wildlife inventory and monitoring efforts emphasize waterfowl, endangered species, and game species. Nongame species receive limited attention (66). Few refuges monitor activities on important adjacent lands, so data sets are incomplete and not representative of the whole ecosystem (66). Some

U.S. FOREST SERVICE

Many western rangeland have been overgrazed by cattle (land on right side of fence), causing declines in biodiversity, loss of soil richness, and increased erosion. Some of these ecosystems are under continuous stress and utilized beyond their carrying capacity.

managers only inventory animals found on the refuge, and some inventory both animals and plants. There is no explicit statutory mandate to conduct inventory and monitoring activities on Wildlife Refuges (66).

There is no systematic mechanism for inventorying and monitoring resources in the Wilderness Preservation System as a whole. Inventory and monitoring efforts for Wilderness Areas are generally subsumed in the inventories of each land-management agency that contains them. Most efforts focus on the most visible impacts, whereas monitoring for more subtle changes in air quality and vegetation status are ignored because adequate funds and personnel are not available. Both the Forest Service and BLM have explicit statutory mandates to inventory their resources, including those in Wilderness Areas. Despite this mandate, many units have not been inventoried (164), and the most detailed inventories are conducted for timber resource lands-not Wilderness Areas (66). Only about 15 percent of BLM-administered land has been inventoried according to minimum standards for vegetation set by USDA's Soil Conservation Service. Less than 5 percent of BLM lands have been inventoried for their wildlife habitat, according to BLM's Habitat Inventory and Classification System, and less than 5 percent of BLM riparian areas and wetlands have been inventoried, according to a parallel inventory system for wetlands (66). In addition, a comprehensive listing of fragile or endangered species is not available, and very few species are included in BLM's Threatened and Endangered Species Data System (66).

Since the early 1980s, the Forest Service has promoted a system--called "Limits of Acceptable Change'—for detecting changes in the conditions of wilderness resources and for guiding management activities. Under this step-by-step approach, issues of concern are identified, indicators of condition are chosen, standards for the condition of wilderness resources are set according to these indicators, and management activities are designed and chosen based on the entire evaluation (113). However, the success of this management tool relies heavily on complete and accurate inventories and routine monitoring of changing conditions. According to a 1988 survey, 76 percent of wilderness managers had not used this tool for wilderness management (164).

In response to the public's concern about a wide range of environmental impacts, such as acid rain and the subdivision of large forest tracks for residential use, Congress directed the Forest Service to initiate a program to monitor the health of the Nation's forests (Forest Ecosystems and Atmospheric Pollution Act of 1988, P.L. 100-521). Forest health monitoring under this act is carried out by the Forest Service, EPA, and State forestry agencies (132).

POLICY OPTIONS

■ The Policy Challenge

Climate change threatens the security of the Nation's investment in natural areas. Substantial land, money, and time have been invested in establishing various systems of natural areas throughout the country to ensure that they are protected for future generations to enjoy. A variety of problems, such as fragmentation, pollution, and overuse, faces natural areas today, and climate change will likely compound these problems and pose new threats to protected natural areas.

The optimal climatic regime for many natural area resources may shift to well outside the legislatively established boundary that protects them. It is not clear how climate change will affect certain species in protected natural areas, but it is certain that species composition will change, and that research to establish baseline information and to detector anticipate that change is currently inadequate to inform decisionmaking. It is also unclear which species will adapt, migrate, or become extinct. However, it is clear that development and fragmentation around and within natural areas are already contributing to species loss and greatly inhibit any ability to adapt or migrate. Climate change may affect the ability of land-management agencies to protect biodiversity and rare species and provide certain types of recreation opportunities. This may affect the ability of land-management agencies to protect biodiversity and rare species and provide certain types of recreational opportunities.

The management philosophies and preservation goals for natural areas may simply be untenable under climate change and may have to be modified. To minimize loss of some resources, intervention, protection, and acquisition approaches may need to be altered. With the high level of uncertainty surrounding the nature of climate change and its regional impacts, it is difficult to identify exactly what should be done to minimize adverse effects on natural areas. However, climate change presents a long-term strategic dilemma for natural area management that needs to be considered now (see box 5-B). Although estimates cannot be made of how much of which types of habitat will be lost, some types of habitat loss due to the dual impacts of climate change and human activity will likely occur despite attempts to adapt.

While addressing threats that are currently affecting federally protected natural areas, there are many ways to prepare for climate change in natural areas that will minimize its impacts.

Congress could help combat the factors that might inhibit adaptation to climate change by approaching land management on a larger, ecosystem-oriented level. Although the definition of "ecosystem management' or how it should be implemented is not clear, some models are beginning to emerge that generally include large-scale management and cooperation. Congress could help agencies combat stresses that could inhibit adaptation to climate change by building from or supporting existing research and development models, by supporting research and monitoring on a regional scale, by supporting Federal agency activities that seek to pursue the ideals of ecosystem management, and by providing incentives for States and private landowners to participate in ecosystem-oriented programs. Many of the options described below could be used to further the ecosystem management concept.

The following policy options fall into two broad categories: strategic information gathering and enhanced protection. Despite this categorization, which splits "research" and "management' issues, the need for strong links between the two cannot be stressed enough. Research that might help guide future management of protected natural areas is not useful if the information is not made available and effectively communicated to managers and decisionmakers.

Strategic Information Gathering

A better understanding of how ecosystems change over time, interact with one another, and respond to climate variables and management activities is a necessary frost step in coping with climate change in natural areas. The policy options for research and for inventorying and monitoring are summarized in table 5-5.

Table 5-5-Options for Strategic Information Gathering

Research
- Increase funding for the "Ecological Processes" research area in the U.S. Global Change Research Program.
- Make research on natural resources a key component of a broadened global change program.
- Direct the National Academy of Sciences, the Office of Science and Technology Policy, or an independent commission to assess the applicability of ongoing environmental research to provide long-term guidance for natural resource protection under climate change.
- Support coordinated research in federally protected natural areas.

Inventorying and monitoring
- Create a national program for inventory and monitoring.
- Create a line item in agencies' budgets for inventory and monitoring activities.
- Direct agencies to identify principal gaps in inventory and monitoring activities within existing programs.
- Support programs that have the most urgent inventory and monitoring needs.

SOURCE: Office of Technology Assessment, 1993.

Strengthen *Research Efforts*

Even if climate scientists determine the exact rate and nature of climate change tomorrow, land-management experts would not know how to respond appropriately. Research in federally protected natural areas is currently focused on immediate management issues, and very little research is being done to provide fundamental, long-term data (e.g., on species response and sensitivity to various climate variables, species interactions and dependence on one another, restoration ecology, preserve design, corridor design and effectiveness, and transplantation ecology).

A commonly cited solution for accommodating species shifts in a fragmented landscape is to facilitate species or ecosystems migration by establishing corridors or by transplanting species to their ‘‘appropriate’ new range. Although theoretically possible, the knowledge base for such options is very incomplete. Pilot projects are ongoing in some places, especially for wetlands (see box 4-A). Research activities that do address these issues are often carried out in centers separated from where management and decision-making take place, so they are less able to directly influence management.

Option 5-1: *Increase funding for the “Ecological Processes’ research area in the U.S. Global Climate Research Program. The* Subcommittee on Global Change Research under the Committee on Earth and Environmental Sciences (see fig. 3-1) has prioritized global change research for all scientitfic disciplines to help guide Federal funding of the U.S. Global Change Research Program (USGCRP). Under this structure, “Ecological Processes” is the third-highest (out of seven) national priority research area for global change (see fig. 3-2). However, 17 percent of the USGCRP budget is allocated for research under ecological systems and dynamics. In 1993, of this $224 million, 66 percent ($148 million) is for NASA programs, 15 percent ($37 million) is for USDA (25), and 4 percent ($9 million) is for DOI.

Increased funding for land-management agencies to carry out ecological research related to global change (e.g., larger spatial and longer temporal scales) would more directly address management concerns. Whatever the funding source, relatively modest funding increases spread over a few years could significantly help to advance the understanding of ecological systems under climate change (see ch. 3).

Option 5-2: *A-fake research on natural resources a key component of a broadened global change program.* Arguably, research that would most help prepare for climate change in natural areas (i.e., on reserve design, migration patterns, and translocation ecology) is not applicable solely to the climate change problem. Such research would also be valuable for other environmental goals such as preserving biodiversity, conserving rare species, and mitigating impacts from landscape fragmentation. In fact, climate change may not be the most compelling reason to conduct the kind of research needed for long-term protection of natural areas. Therefore, the existing USGCRP, now primarily a climate research program, may not be the most appropriate mechanism for promoting natural resources research that has significant application to a much broader set of global environmental problems.

On the other hand, no other mechanism coordinates research on global-scale environmental problems across the Federal Government under a prioritized scheme to accomplish specified scientific goals and objectives. USGCRP offers the best alternative to agency-by-agency research on global environmental problems. If USGCRP is expanded to address broad issues of global change, it could better promote research for long-term protection of natural areas on several fronts. (See ch. 3 for more discussion of these issues.)

Option 5-3: *Direct the National Academy of Sciences, the Office of Science and Technology Policy (OSTP), or an independent commission to assess the applicability of ongoing environmental research to provide long-term guidance for* *natural resource protection under climate change and other global changes. It is* evident that one of the most prudent approaches to natural area conservation under climate change is more coordinated management on the ecosystem or regional scale. This approach would also help address threats to biodiversity and maximize possibilities for species survival under climate change. However, relatively little research is being done on ecosystem or regional-level interactions (30, 70)---most research is site- or species-specific. Several efforts in various agencies could be supported and expanded to facilitate ecosystem-level research (see boxes 5-F and 5-L).

Several recent studies have called for an assessment of U.S. environmental research (see ch. 3). The Federal Government spends about $900 million on environmental research annually.[33] Although this figure is huge (almost as much as the entire USGCRP budget; see ch. 3), the term "environment" is also quite broad. It is unclear how much of the research is applicable to unmanaged ecosystems, and how much is coordinated to provide answers for long-term problems like climate change and biodiversity. A task force could attempt to categorize this pot of money for environmental research in several ways: How much is being spent on various natural resources: air, water, land, wildlife, soil, forests, crops? How much is being spent on various environmental problems: pollution, biodiversity loss, climate change, contamination, hazardous waste, natural disasters? How much is being spent on long-term issues?

A study conducted by the National Academy of Sciences, OSTP in the Office of the President, or an independent commission could examine programs addressing these areas, including programs within USGCRP, and suggest how they could be expanded, augmented, or integrated. Such a study could build on NSF's ongoing analysis of environmental research (unpublished).

Option 5-4: *Support coordinated research in federally protected natural areas. The* research programs for Wilderness Areas, National Parks, and National Wildlife Refuges are uncoordinated or inadequate. Because the agencies that administer these areas have traditionally been seen as management agencies, scientific research has not been a high priority--except to address immediate, agency-by-agency management concerns. However, with the uncertain impacts of climate change coupled with existing threats on natural area resources, informed management decisions will be nearly impossible in the future without a strong research effort. The National Academy of Sciences has recommended the development of a National Environmental Research Plan (85). This plan would set a research agenda and identify agency responsibilities.

NSF's Long-Term Ecological Research Program conducts basic ecological research and long-term monitoring at 18 sites (see box 5-L). This program could be investigated as a model for long-term research in the Federal system of natural areas. Although LTER research is not formally focused on management activities, much of this basic research has contributed to a better understanding of specific sites with direct implications for future management (42). NSF also supports basic research in areas such as sensitivity of species to climate change and restoration and translocation ecology.

A formal mechanism for linking research results to management decisions and planning should be incorporated into any natural areas research agenda. There is a danger that if research responsibility is taken away from the land-management agencies without sufficient links to management in place, land managers will not be aware of or will even be uninterested in scientific results that could lead to more effective management.

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[33] J. Gosz, Executive Secretary, Subcommittee on Environmental Biology, Committee on Life Sciences and Health, Federal Coordinating Council for Science, Engineering, and Technology, personal communication, Sept. 14, 1993.

Strengthen Inventorying and Monitoring Efforts

Adequate information about the existing state of U.S. resources in natural areas and elsewhere is an important element in a strategy to address the impact of climate change in these areas. Baseline information on species and their ranges are not available for all species or species types in the United States. In addition, virtually no information is available on land-use patterns that might affect those species. Inventory and monitoring programs are usually the last to get funds and the first to be cut in a budget crisis (83, 177). Many monitoring programs that have been established in protected natural areas have been discontinued because of personnel changes, policy alterations, or budget cuts (177).[34] Baseline information is needed on the status and trends of vegetation cover, plant distributions, animal distributions, soils, and water resources to detect and monitor climate-induced changes. All Federal agencies conduct some type of inventory as a matter of policy, but these efforts vary widely in completeness and quality, are not consistently implemented and funded, and are not coordinated at the national or even agency level. In addition, many species and ecosystems are not found in the Federal system of preserved areas and, therefore, they are not included in any Federal inventory and monitoring efforts. The Federal Government could play a key role in improving inventory and monitoring activities.

Option 5-5: *Create a national program for inventory and monitoring.* A nationwide inventory and monitoring program with consistent and comparable inventory methods across all Federal and State agencies would help assess the state of the Nation's resources. Such a program could help facilitate regional planning by providing a broad understanding of the resources within various regions, guiding Federal acquisition and conservation incentive programs, and detecting large-scale changes in natural areas.

An interagency task force could evaluate existing efforts, identify shortcomings, and outline a national program that addresses gaps in data gathering. Nationwide minimum standards, methods, and, possibly, reporting procedures for inventory and monitoring activities could be developed. All Federal agencies with land-management responsibilities could be required to adhere to these standards, and States and private organizations could be encouraged to adopt these standards as an eligibility requirement for receiving conservation-oriented Federal grants. The National Biological Survey within the Department of the Interior could help integrate activities within DOI and serve as a liaison with other groups. Although the NBS could take the lead in this effort, it is essential that the Forest Service and other USDA agencies, the National Science Foundation, the Environmental Protection Agency, and the Department of Energy be included in the task force. In addition, State agency representatives and private organizations, with existing inventory programs, such as The Nature Conservancy should also be included. Several existing efforts, such as EPA's Environmental Monitoring and Assessment Program (EMAP), the U.S. Fish and Wildlife Service's Gap Analysis Project (GAP) program, and The Nature Conservancy's National Heritage Program, could be expanded or incorporated into an integrated Federal effort (see box 5-F). At the request of the Secretary of the Interior, the National Research Council has formed the Committee on the Formation of the National Biological Survey to study these issues.

A national inventory and monitoring program should include a clearinghouse, possibly through NSF or NBS (see box 5-L), for storing and evaluating information so that it would be easily accessible to interested parties.

[34] For example, in FY 1993, BLM eliminated 6 of its 16 acid-rain stations to release about $30,000 for other BLM activities. Several of the six stations had been in operation for 10 yearn and had been maintaining data sets to monitor the health of forests and the effects of acid rain. Continuation of this longer-term record was lost as a result of these cuts.

In developing a nationwide comprehensive inventory and monitoring system, it is important to ensure that the minimum standards and methods can be reasonably applied to all types of land under all types of ownership and management. Many National Parks and other protected natural areas, for example, have special inventory and monitoring needs, depending on their missions and specific legislative purposes (e.g., managing threatened and endangered species or encouraging visitor use). Whatever standards are developed should allow enough flexibility to accommodate the needs of individual areas while achieving national objectives.

Finally, a concerted effort to connect, in a timely manner, the information contained in a national inventory and monitoring program to the resource management and land-use planning process is vital. If these connections are not adequately addressed, the gap between research and management could increase with the establishment of a separate research agency in DOI.

Option 5-6: *Create a line item in agencies' budgets for inventory and monitoring efforts.* A line item in agency budgets will ensure that inventory and monitoring is receiving consistent, adequate, and long-term attention. However, although a budget line item may help ensure more specific attention to the activity, it does not guarantee consistent or long-term funding. It may, in fact, become a more visible target for cutting in budget-stressed times. NSF's Long-Term Ecological Research (LTER) Program is funded on 5-year cycles (see box 5-L). A similar funding cycle for other agency programs might help give them more long-term funding stability.

Option 5-7: *Direct agencies to identify principal gaps in inventory and monitoring activities within their existing programs.* Congress could address inventory and monitoring issues at the agency level by focusing on the essential information that is missing from existing programs. Agencies could be directed to develop a priority list for inventory and monitoring needs with cost estimates. This priority list could be used to guide funding decisions for agency activities over a period of time. However, it is likely that these lists will vary according to each agency's missions.

Option 5-8: *Support programs that address the* most urgent *inventory and monitoring needs.* A national-scale survey of the Nation's biological resources (even if it is a broad-brush survey) is needed now to help foster regional land-use planning and to provide better protection, now and in the future, for the Nation's natural areas. Remote-sensing technologies and geographical information systems (GISS) are powerful tools that provide regional information on biological resources, topography, and land use. The Fish and Wildlife Service's **Gap** Analysis program synthesizes information from satellites, State heritage programs, and Federal agencies to identify vegetation-cover types, potential habitat for particular species, and areas of potentially high species richness as well as information on land-use and protection status (see box 5-L). Support for this program could produce a crude national inventory by **1998.** Although EPA's EMAP project is another national-scale inventory and monitoring program that may be valuable in detecting long-term trends and assessing the status of various resources, methodologies are still being developed. Land use and ownership are currently not part of the program, and its spatial resolution may be too coarse to guide regional-scale planning.

Enhanced Protection

Federally protected natural areas are a haven for some species, and they have become a central part of species-protection efforts. But natural areas and the habitats they protect are not immune to human disruption-habitat destruction, pollution, and other stresses threaten more and more species with extinction (126), and climate change may exacerbate these stresses. Many federally protected natural areas are already too small to contain functioning ecosystems for many large animals (29, 51, 76). Because of these combined factors, existing natural areas may be less able to protect species in the future; other currently unprotected lands may become more important for species survival. Protection for existing and future natural areas can be enhanced in several targeted ways through both direct and indirect Federal actions and by encouraging multi-government-level partnerships. Options for enhanced protection are summarized in table 5-6.

Table 5-6—Options for Enhanced Protection

Direct Federal action (acquisition and management)
■ Direct agencies to modify their criteria for land acquisition to include underrepresented ecosystems, long-term survivability and connecting or enlarging land parcels.
■ Increase appropriations for the Land and Water Conservation Funds to give States and agencies more power to acquire land and provide easements.
Indirect Federal action (incentives and cost-sharing)
■ Use current conservation incentive programs administered by the Secretaries of Agriculture and Interior to enhance the Federal effort to protect natural areas.
■ Encourage ecosystem-level conservation at the State level by funding the Fish and Wildlife Conservation Act of 1980 (P.L. 96-366).
Multilevel partnerships
■ Use "cooperative research and management funds" to foster cooperative management among agencies.
■ Create a Federal Coordinating Council for Ecosystem Management.

SOURCE: Office of Technology Assessment, 1993.

Direct Federal Action

Direct Federal action-such as revising agency mandates and modifying criteria used for acquisition, land transfers, and exchanges-could be used to enhance the Federal system of natural areas and make them less vulnerable to climate change.

Acquisition policies for the National Park Service and the Fish and Wildlife Service do consider biological diversity and reflect a desire to include a variety of ecosystem types. In addition, all agencies that administer natural areas have some kind of size requirement in their acquisition policies that gives preference to larger areas for protection. No acquisition policy gives preference to areas that are adjacent to or link existing natural areas-a criteria that could greatly benefit the preservation of natural areas in the future. Biodiversity is not considered in USDA Forest Service and BLM wilderness designations. In addition, although a variety of ecosystems is federally protected, there is little duplication and many ecosystems types are still unprotected. One study revealed that of 135 ecosystem types, 24 percent were inadequately represented and 7 percent were not represented in any Federal land system (see figs. 5-8 and 5-9).[35] Another study of just the Wilderness Preservation System found that of 233 ecosystem types, 65 percent were found to be inadequately represented (occurring on less than two units of 1,000 acres or more) and 21 percent were not represented (32).[36]

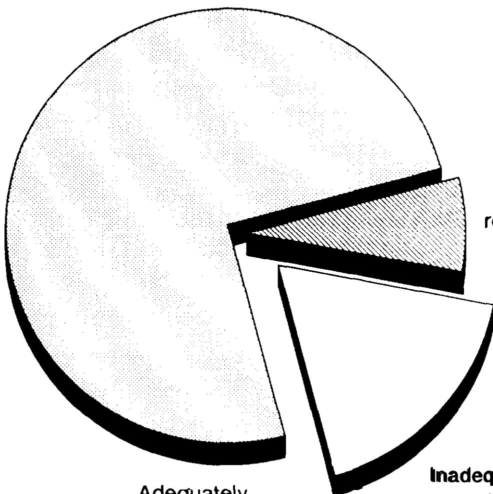
Research Natural Areas (RNAs), first officially established in the 1970s as lands from each land-management agency designated for special research and monitoring, were to form a system that would have representatives of all ecosystem types (57) (see box 5-L).[37] The Federal Committee on Ecological Reserves, established by the Johnson administration, was to explore possibilities of expanding the RNA system to include additional Federal lands as well as State, local, and private lands, and to develop guidelines and criteria for management. Though it has not been formally disbanded, the committee has not met since 1979 due to lack of funding and staff (7).

[35] The study used 1982 ownership maps based on Kuchler's Potential Natural Vegetation Types (33). "Inadequately represented" meant that relatively small acreages were protected in the Federal system of protected lands (including National Forests and BLM-administered Public Lands as well as Indian reservations).

[36] This study used a slightly different delineation of ecosystem types as specified for the Forest Service's wilderness evaluations.

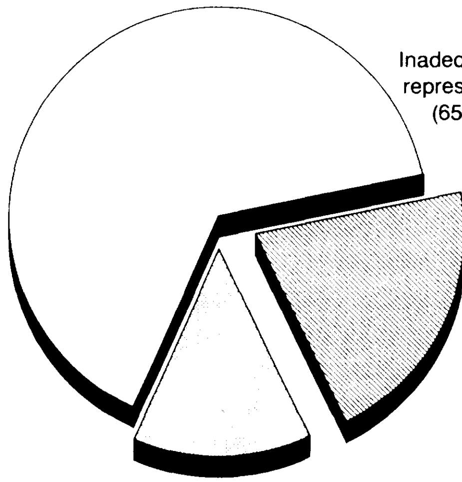
[37] Although both the USDA Forest Service in the 1920s and the National Park Service in the 1930s set aside some of their lands for research and monitoring, these lands did not become part of a coordinated Federal system of Research Natural Areas until the 1970s.

Figure 5-8-Ecosystem Types Represented on Federal Land



SOURCE: Office of Technology Assessment, 1993.

Figure 5-9-Ecosystem Types Represented in National Wilderness Areas



SOURCE: Office of Technology Assessment, 1993.

Because Federal acquisition means that lands are removed from the local tax base, the potential exists for negative third-party effects on the local economies in areas where land acquisitions take place. The main Federal program to compensate for this loss, the payment-in-lieu-of-tax program, may not be perceived as adequate compensation in some counties (127). In addition, Federal land acquisition is a particularly volatile issue in the West. Many local communities perceive Federal acquisition as a "taking" of their land and, effectively, an invasion of their "right" to it. Therefore, there may be substantial political resistance to new acquisitions in some areas. Congress could avoid, or at least temper, some of these conflicts by protecting corridors or adjacent lands through easements or other incentives where land does not change ownership.

Option 5-9: *Direct agencies to modify their criteria for land acquisition to include under-represented ecosystems, long-term survivability and connecting or enlarging land parcels.* Congress could revitalize the Federal Committee on Ecological Reserves or create another committee with representatives from Federal agencies, environmental groups, States, and citizen advisory groups and direct it to conduct a study to determine what ecosystem types are not adequately represented in the Federal system of reserved and protected lands. Congress could direct the managing agencies to develop long-term strategic "protection plans" for each federally protected natural area system. When designating new Wilderness Areas, National Wildlife Refuges, establishing new National Parks, or acquiring additions, agencies should target areas containing high natural biological diversity, unrepresented ecosystem types, areas with climate-sensitive species, areas with unique biotic communities, and areas adjacent to existing protected areas. It is not the explicit policy of any land-management agency (except the Fish and Wildlife Service) to target future acquisitions to protect or augment existing holdings and make them larger, to link holdings together, or to maximize the variety of ecosystems or the level of biodiversity.[38] Yet, effectively enlarging protected areas, creating appropriate migration corridors, and ensuring that all ecosystem types are under a protection system are frequently cited as the best ways to begin preparing natural areas for climate changes (13, 29, 94, 96, 111, 161). However, whether or not an area can ultimately be managed or acquired to protect a natural area may depend more on political factors than on ecological factors because of the potential for negative third-party effects.

Protection strategies could include options for securing and quantifying necessary water for natural areas (see box 5-H) and for helping to mitigate internal and external stresses. Agencies could outline how survivability would be achieved through integrated and coordinated efforts with other Federal agencies as well as with State, local, and tribal governments and private organizations.

D. DOWNING © 1983

Fragmentation of habitat, by human development in remote and wild areas, has led to the dispersal and decline of many species. Wildlife that depend on corridors of habitat for food and cover have been forced to survive with severely limited resources.

Indirect Federal Programs

The Federal Government has initiated several programs that encourage State and private landowners to protect the natural resources on their land. These programs were initiated for a variety of reasons: to slow erosion, to slow wetland loss, or to protect game species. Few of these programs are designed to augment the Federal protection effort. And, with the exception of programs for game species, there are few Federal "incentive" programs to protect species while populations are still healthy. Addressing both or either of the other issues would create more coherent programs better suited to aid the Federal effort to protect natural areas while at the same time achieving the broad goals for which the programs were established.

Option 5-10: *Use current conservation incentive programs administered by the Secretaries of Agriculture and Interior to enhance the Federal effort to protect natural areas.* Numerous incentive programs already in place aim to encourage land conservation. The Conservation Reserve Program and the Wetlands Reserve Program offer easements to landowners who enroll highly erodible lands and wetlands into the program (see ch. 4). The Federal Aid to Fish and Wildlife Restoration Programs (the Dingell-Johnson and Pittman-Robertson programs) are Federal-State cost-sharing programs funded by excise taxes on fishing and hunting equipment for projects that benefit fish and game. The Forest Service's Forest Stewardship Program encourages forest conservation by providing financial assistance to private landowners to prepare and implement an approved stewardship plan. However, none of these programs are targeted to augment the Federal effort embodied in the Federal natural area systems. Many of these programs could be used to effectively enlarge protected natural areas, to create links between habitats, or to preserve biodiversity or special vegetation types on private land.

Administering agencies could give preference to lands that are adjacent to, link up with, or otherwise augment federally protected land.

[38] In designating new Wilderness Areas and National Parks, however, some consideration is given to unrepresented Or underrepresented ecosystem components.

Alternatively Congress could increase the easement benefits or the Federal share of payment offered for desirable lands.

Option 5-11: *Encourage ecosystem-level conservation at the State level by funding the Fish and Wildlife Conservation Act of 1980. Federa1 laws are* now in place to protect both game species and endangered species on non-Federal land, but there is no mechanism to protect species between the two extremes of "hunted" or "totally protected" until they decline to the point of near extinction. The Fish and Wildlife Conservation Act passed in 1980 could fill a large gap in the Federal protection effort and help minimize species loss under climate change. This act establishes a cost-sharing program with the States for nongame wildlife-conservation projects. Funding for the program must be congressionally appropriated, but no money has ever been appropriated. The program could augment Federal protection efforts especially if geared more broadly to protect ecosystems rather than individual species.

Partnerships Among Different Agencies and Levels of Government

Because of shortages in funds and lack of large pieces of available land to establish new protected natural areas, protection of natural area resources will require unprecedented levels of coordination and cooperation in management and research among Federal agencies; State, local and tribal governments; private landowners; and interest groups. There are many examples of innovative protection mechanisms to draw on in establishing effective partnerships. Most use a graded management system, where the innermost areas receive the most strict protection and more uses are allowed for the outer areas. This is the management scheme supported by Unesco's Man and the Biosphere program (MAB), The Nature Conservancy's Last Great Places Initiative, and the Pine Barrens National Preserve in New Jersey. All of these programs and others are outlined inbox 5-F. A high degree of local participation and support, willingness to compromise, and adequate compensation for those who sacrifice development rights are vital to project success (68, 168). Congress could encourage cooperative efforts and spur local support by funding cost-sharing programs and challenge grants, by linking a portion of agency funds with cooperative efforts, and by offering other incentives, such as income tax breaks, to those who are willing to participate in conservation and protection programs.

In addition, partnerships are becoming a popular way to enforce the Endangered Species Act (P.L. 93-205). Under Section 10 of the revised act, a party may be permitted some destruction of an endangered or threatened species if a habitat conservation plan (HCP) is prepared with the cooperation of Federal, State, and local governments to arrange for the "permanent' protection of critical habitat elsewhere. The development of an HCP often results in the establishment of a federally protected natural area. If this method becomes more widely used to protect endangered species, the Federal Government will need to ensure that national interests are protected during negotiations. (See box 5-D for a more detailed discussion of the Endangered Species Act and HCP.)

Whatever the protection mechanism, efforts should aim to create a diverse network (regionally and biologically) of protected areas of maximum size (111). Although federally protected natural areas will remain the focus of conservation efforts, a complete, diverse, and representative preserve network will require consideration of other Federal systems as well as State and private holdings.

Option 5-12: *Use "cooperative research and management funds" to foster cooperative management among agencies.* Under the current funding structure, there is little financial incentive for Federal land managers to actively participate in cooperative ventures with other agencies, State governments, or private parties. Congress could appropriate a certain sum of money for each agency with terrestrial research and management responsibilities. These monies could be used for multiagency or multigovernment-level projects that address identified research priorities. Congress could also appropriate funds for regionally based, cooperative pilot projects. These projects could include the development of interagency strategic kind-management plans.

Many programs already in place in some agencies could be expanded and supported with these funds. Both the Forest Service and BLM have Challenge Cost Sharing Programs in which matching funds are made available to the States for habitat-improvement projects. HCPS under the Endangered Species Act are developed through a coordinated effort with Federal agencies, landowners, industry, environmental groups, and developers. Although not centered in any Federal agency, Unesco's MAB is an example of a regional research effort involving many Federal agencies.

Option 5-13: *Create a Federal Coordinating Council for Ecosystem Management.* Congress could build from the idea that produced the Federal Coordinating Council for Science, Engineering, and Technology, to create a Federal Coordinating Council for Ecosystem Management that would provide a forum for facilitating cooperative management at the national level. This council could evaluate interagency projects and make recommendations regarding needed collaboration. Such an evaluation may identify the extent of existing research or activity in this area, and enable an easier identification of areas in need of more emphasis. Although this council could be effective in facilitating integrated activity at the national level, the successful implementation of national programs would rely on incentives and support for "ecosystem management," or cooperation at the land-management (grassroots) level.

FIRST STEPS

Because money to implement all the above options and the scientific understanding of how climate change will affect natural areas are limited, the following frost steps represent reasonable actions for facilitating adaptation to climate changes in natural areas. The first steps identified here are those that meet one of several criteria:

—they should be undertaken early because they will take a long time to complete;
—they address "front-line," or urgent, issues that need attention first in order to make informed policy decisions in the future;
—they can be approached through mechanisms already in place or efforts already underway;
—they are beneficial for reasons other than helping to prepare for climate change; or
—there is a near-term 'target of opportunity."

These first steps begin to address the research, monitoring, and protection needs identified in this chapter. By starting with these options, the Nation can respond to the impacts of climate change in federally protected natural areas while strengthening its commitment to natural area protection in general. These are first steps to pursue because of present climate change concerns; they are not all the things one could do to prepare natural areas for the future impacts of climate change.

- Use the National Biological Survey to assess biological and ecological inventory and monitoring needs. A nationwide 'map' of biological resources, topography, land use, and protected areas is needed now. Future strategies to protect natural areas and their resources will require a national picture of what biological resources currently exist and where they are located, what lands are under protection, and how adjacent lands are used. Simply, a baseline resource map is necessary before detection of long-term changes in resource conditions can be made and protection efforts modified. A national inventory and monitoring program would also be beneficial for protecting endangered species and biodiversity.

The new National Biological Survey in the Department of the Interior is the closest mechanism to a single, multiagency, national effort to address global change issues for biological resources. Because the NBS is in its formative stages, it presents a clear opportunity to implement some of the options outlined above. However, unlike the U.S. Geological Survey, the only agency that deals extensively with geological research and information, there are several agencies outside DOI with responsibilities for biological resources. The ideal, nationwide NBS program would effectively incorporate the activities of these other agencies as well as State and private organizations (see box 5-L). To do so, the NBS will have to create a formal mechanism to link and coordinate with activities in other agencies.

Because most basic ecological research is funded through NSF, that agency should be actively and formally involved in any comprehensive ecological research. Other agencies that manage biological resources should also be involved. This office could be charged to produce a document that synthesizes the condition of the Nation's biological resources and the state of the scientific understanding about how they work and interact.

Congress could ask the NBS to develop a priority plan for expanding protection of natural areas to include all ecosystem types and areas with environmentally sensitive species and high biological diversity. The plan could incorporate a variety of techniques including acquisition, easements, cooperative management, incentive programs, and cost-sharing programs.

- Support basic research on key gaps in our understanding of ecosystems, such as: 1) past climate changes and corresponding species responses, 2) restoration and translocation ecology, 3) the effectiveness of corridors and buffer zones, 4) the development of ecological models, and 5) the effect of elevated CO_2 on assemblages of plants and animals. Basic research in these areas is needed now to determine how species might respond to climate change and how to best provide for their protection in the future. Agencies could attempt to redirect existing funds in the USGCRP or procure new funds for addressing these basic ecological research needs under the "Ecological Processes" research area (see ch. 3). Alternatively, NSF, whose mission is to support basic scientific research, could take the lead in supporting these research areas outside the auspices of USGCRP. The new NBS could also be an appropriate vehicle to use in addressing some of the research that directly relates to land-management issues.

- Conduct a review of ecological research within USGCRP and across Federal agencies, evaluate how much long-term ecosystem-level research relevant to climate change, biodiversity and other multidecadal problems is being done, and identify important gaps. A review of all research conducted on "natural resource" has not yet been compiled across the Federal agencies. Existing analyses suggest a great deal of money is spent on research relevant to the environment but how much is useful to understanding long-term ecological problems (such as biodivesity and climate change) is not known.

Further, there is currently no mechanism for consolidating results from disparate research efforts into "general patterns and principles that advance the science and are useful for environmental decisionmaking. Without such synthesis studies, it will be impossible for ecology to become the predictive science required by current and future environmental problems" (70).

An effort to characterize and synthesize ongoing research could help bridge the gap between basic research and natural resource planning. Such a review could be conducted by OSTP, NAS, or an independent commission.

- **Provide funding for the Fish and Wildlife Conservation Act of 1980 to promote natural area conservation and protection at the State level. This** law establishes a Federal cost-share program for "nongame" species conservation. It is already enacted, and many States have prepared initial plans that could qualify for Federal matching funds, making it a target of opportunity to promote natural area conservation at the State level. With some amendments to promote multispecies, or "ecosystem," protection at the State level and adequate funding, the Fish and Wildlife Coordination Act could be used to encourage natural area protection and conservation on State and private lands.
- Direct management agencies to explicitly consider three ecosystem criteria in all future land acquisitions: **1) likely to persist over** the **long term despite current and anticipated stresses, 2) augments underrepresented ecosystems in the Federal natural area holdings, and 3) buffers or connects other preserved land parcels.**

Setting aside a given amount of land within the modem fragmented landscape does not alone ensure that the ecological features for which they are valued will be preserved. To best conserve species, natural areas should include an array of ecosystems and transition zones between them to allow for the many complex interactions that rely on links between different parts of the landscape.

By asking agencies to incorporate such concerns into future acquisitions, Congress could minimize future geographic fragmentations and use limited monies to maximize the range of protected ecosystems.

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PRESERVES-FIRST STEPS

- Use the National Biological Survey to assess biological and ecological inventory and monitoring **needs**
- Support basic research on species and ecosystem sensitivity to climate change, restoration and translocation ecology, and the design and effectiveness of corridors and buffer zones
- Conduct a review of ecological research within the U.S. Global Change Research Program and across Federal agencies
- Provide funding for the Fish and Wildlife Conservation Act of 1980 to promote natural area conservation and protection at the State level
- Direct agencies to acquire areas that are likely to persist in their natural state over the long term, link or buffer existing holdings, and increase representation of ecosystems not currently under Federal protection

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Forests 6

Status

- Currently stable resource.
- Significant area of public forest—with increasing limits on *timber* management.

Climate Change Problem

- Shifts in the ideal range for tree species.
- Potential for significant forest decline or loss to fire, insects, and disease.
- Potential dislocations within local or regional economies.

What Is Most Vulnerable?

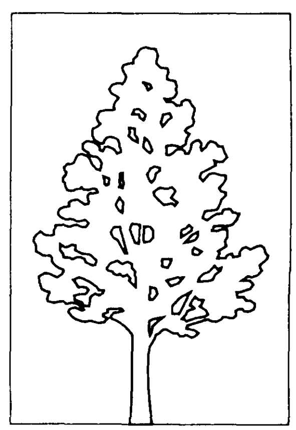
- Forests in regions subject to increased moisture stress.
- Species or forests with little tolerance to climate changes.

Impediments

- Slow process of tree growth; reliance on older trees for products and services.
- Knowledge limits: climate sensitivity of species; large-scale restoration.
- Restrictions on public forest management response.
- Limited incentives for private protection of forest environment.

Types of Responses

- **Learn** what is at risk (research on species sensitivity; monitor change).
- Deal with the potential for loss of species (seed banks, mass propagation techniques, experiment with forest restoration techniques).
- Prepare for possibility of large-scale mortality (planning process, private incentive programs, technologies for use of salvage wood).
- Increase adaptability of forest industry and forest-dependent communities (information, product research).



NOTE: Many parts of this chapter have been drawn from contract papers prepared by W.H. Smith for an OTA workshop held June 1992 (76, 77).

OVERVIEW

Forests cover roughly one-third of the U.S. land area shape much of the natural environment, and provide the basis for a substantial forest-products industry. Forest management has always been a challenging endeavor due to the long-lived nature of forests, the varied random events that perturb them, and an incomplete understanding of forest development and structure.

Considerable uncertainty is associated with predictions of climate change and its effects on forests. However, global warming could shift the ideal range for some North American forest species as much as 300 miles (500 kilometers)[1] to the north. Such a shift would almost certainly exceed the ability of the natural forest to migrate (34, 35, 56, 75). Forests stranded outside their ideal climatic range could suffer from periods of declining growth and increased mortality from climate-related stresses such as insects, disease, and fires. Some forest systems may collapse, and species or unique populations may be lost from isolated ranges. Although mortality and the decline of a forest ecosystem can occur quite rapidly, the regrowth of a productive forest may take many decades or even centuries. A natural forest system will not necessarily regrow quickly into similar or equally valuable forest cover.

Both the lifetime of trees and the timescale for climate change are multi-decadal. Therefore, most trees living today could beat some risk from climate change. The most vulnerable forests may be those in regions already subject to moisture stress, as in the dry continental interior. Forests in coastal regions of the Southeast may be at risk from rising sea levels and damaging wind storms, leading to flooding and saltwater intrusion. Forests with small or highly fragmented ranges may be lost, perhaps including those at the upper elevations of mountains, which have nowhere to migrate.

Of course, not every change in the forest results in an economic or aesthetic loss or is reason for public concern. Forests have always changed over time and will continue to do so with or without climate change. The significance of any change differs across forest types, determined by the nature of ownership, the values for which the forest is managed, the magnitude of change, and the rate at which change occurs. Some decline in growth rates or moderate increases in tree mortality may be acceptable on wilderness lands; the same decline would be of great consequence on industry timberland. For many users of the frost and industries dependent on the forest resource, it is the rate at which change occurs that will matter most. For example, if climate change occurs gradually, the forest-products industry might adjust with little cost, eventually focusing on more suitable locations or adopting technologies that make best use of available wood supplies.

If climate changes quickly, impacts could be quite different. The potential for widespread mortality or extinction of some forest species is of general concern. Substantial forest decline--with losses in species, uniquely valued forest stands, or entire ecosystems--would put at risk much of the social and environmental value that the Nation's forests now provide. Rapid and unanticipated changes in the forest could lead to extensive local and regional impacts, including:

- losses in species, uniquely valued forest stands, or entire ecosystems;
- widespread catastrophic damage from fires, insects, or disease; and
- extensive dislocations within local or regional economies.

The threat of these potential impacts appears to be the primary justification for public action in preparation for the uncertainties of climate change.

The challenge of these threats to managers of the forest resource is the limited extent to which

[1] To convert miles to kilometers, multiply by 1.609.

adaptive responses are possible. Forest lands range from the managed industrial forest to the purposefully unmanaged wilderness reserves (discussed in ch. 5). In between, lie large areas of *multiple-use forestland-forests* valued for services other than just timber production or wilderness. Even the industrial forests are not intensively managed by the standards of annual agricultural crops (see vol. 1, ch. 6). Still, the private industry manager does have the latitude and the incentive to respond quickly to limit the extent or duration of any loss in timber. On large areas of public, multiple-use forestland, however, the active management that might buffer the forest from climate risks may be viewed as incompatible with the values for which the forest is held. (The special concerns raised by the threat of climate change to the system of parks and reserves are addressed in ch. 5.) On many other public and private forestland areas, active management may be financially impractical. The challenge is to find unobtrusive and cost-effective means to help ensure that the health and primary services of the Nation's forest resource will not be lost.

The Federal Government can prepare itself to respond to the threats that climate change poses to forests in several ways: by determiningg which forests are at risk (e.g., by supporting research on the sensitivity of various species to climate and monitoring changes in forests); by acting to avoid the potential loss of forest species (e.g., by promoting and improving gene banks, mass-propagation techniques, and forest-restoration techniques); by being ready to react promptly to reduce the threat of large-scale forest mortality (e.g., through fire prevention, pest management, or thinning to promote drought tolerance in forests where such activities are determined to be appropriate); by redirecting incentive programs to encourage improvements in the health of private forests and to discourage conversion of forestland to other uses; and by increasing the adaptability of the forest industry and forest-dependent communities to climate change through support for forest-products research and through incentives for diversification.

This chapter describes the status of forests in the United States today, the functions for which they are managed, and the current understanding of the potential vulnerability of forests to climate change. The chapter then turns to the strategies and actions that could help in preparing for possible changing climate, while being mindful of the uncertainties and sensitive to the purposes for which forestland is held.

THE FOREST RESOURCE

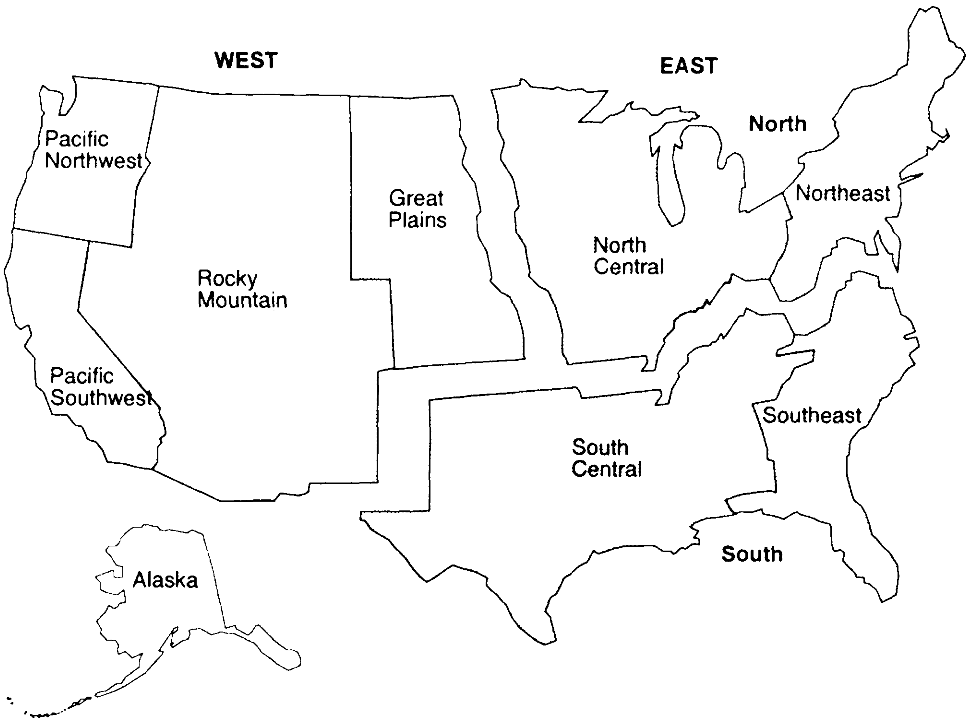
Forests dominate the landscape in much of the United States. They cover roughly one-third (731 million acres, or 292 million hectares)[2] of the Nation's land area and are found in all 50 States (90).[3] These forests are enormously variable, ranging from the sparse scrub of the arid interior West to the lush forests of the coastal Pacific Northwest and the South (see fig. 6-1 for forest regions). In percentage terms, forests are most prevalent in the East, covering over 40 percent of the land. In the drier West, where they are a less significant element of the overall landscape, forests are prominent features in the coastal States and the Rocky Mountains. The density of forest cover across the United States is mapped in figure 6-2, and the regional distribution of forestland relative to overall land area is shown in figure 6-3.

The Nation's forests provide essential fish and wildlife habitat, livestock forage, watershed protection, attractive vistas, and a large array of recreational opportunities. In 1992, for example, there were some 300 million visitor-days of

2 To convert acres to hectares, multiply by 0.405.

3 A considerable additional area of wooded land is found in suburban, urban, and agricultural areas but is not classified as forest. Land is classified as forest only if it has at least 10 percent tree cover (or once had such cover and trees are expected to return), an area of at least 1 acre, and a width of at least 120 feet (37 meters). To convert feet to meters, multiply by 0.305.

Figure 6-1—USDA Forest Regions of the United States



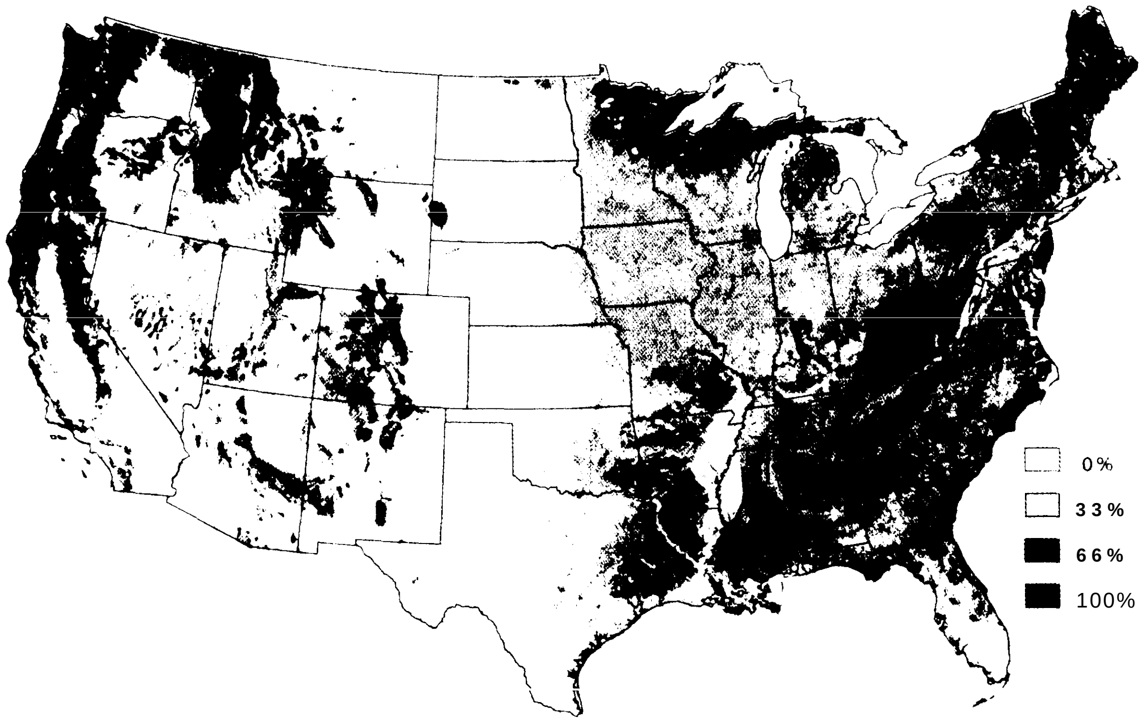
SOURCE: U.S. Department of Agriculture, Forest Service, *An Analysis of the Land Base Situation in the United States: 1989-2040*, General Technical Report RM-181 (Washington, DC: USDA, Forest Service, 1989).

recreational use on Forest Service lands (98). In urban and suburban settings, trees add significantly to property value and can provide a valuable service in shading homes from summer heat. Wooded strips in agricultural areas reduce the drying effects of winds and limit erosion. In New England, the fall colors are a focal point for tourism. The Sequoias and giant redwoods of California are a similar attraction. Some of the various products and services associated with a healthy forest are listed in table 6-1.

In recent years, timber has often been the single most valuable agricultural crop produced in the country (90). Nationwide, in 1990, the forest-product sector[4] employed some 1.5 million people and added about $80 billion to the gross national product (102). Timber is particularly important to the economies of the Pacific Northwest and the South. The industry is also important across much of the northern edge of our Nation. The top four States in terms of earnings from logging are Oregon, Washington, Georgia, and South Carolina (103). California, Oregon, and Wisconsin have the highest earnings from forest-related industries, including paper and lumber processing. In percentage terms, Maine and Oregon are most dependent on the forest resource, with over 8 percent of earnings coming from forest industries. Over 4 percent of earnings in Idaho, Wisconsin, Arkansas, Mississippi, Minnesota, and Montana are generated from employment in the timber industries.

[4] Including primary forestry activity and the secondary forest-products industries such as the pulp and paper-processing industries.

Figure 6-2—Forest Density Within Advanced Very-High-Resolution Radiometer Plxeis



SOURCE: U.S. Department of Agriculture, Forest Service, 1993.

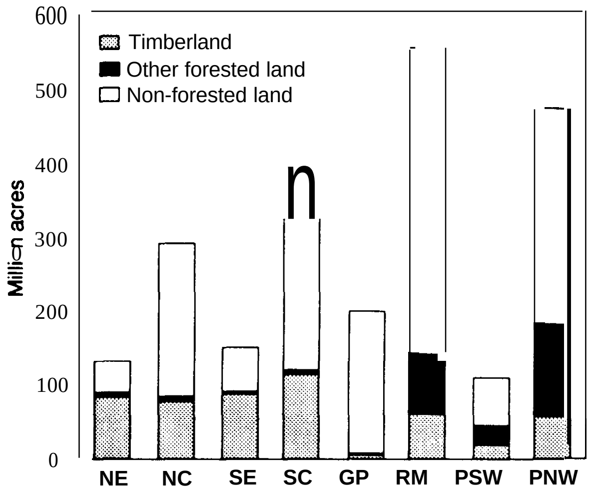
The biodiversity of our forests is a rather different type of value. There are roughly 700 native tree species in the continental United States (44). Some 300 are large tree species that have significant value for current or potential commercial use or for their aesthetic value. Of these, perhaps less than 50 species are used extensively by the forest-products industry. Much attention is directed to the even fewer species potentially useful for plantation forestry. However, extinction of any species could be a threat to the Nation's heritage of biological diversity. In addition, such a loss in forest diversity could represent, or signal, a threat to the future commercial potential of the Nation's forests.

Forestland

Forestland is usually classified according to its timber productivity and availability for timber management. Some two-thirds, or 483 million acres, of U.S. forestland is classified as ***timberland*** (111). This forestland is productive enough to potentially support timber managements An additional 213 million acres of forestland is classified as *otherforestland(11* 1). These forests

[5] Timberland is forestland that is accessible to harvest, not withdrawn from timber management, and capable of a growth rate of 20 cubic feet per acre (1.4 cubic meters per hectare) per year of commercially valued wood. This growth rate is often described as the minimum threshold for potential timber management. In fact, considerably higher growth is typically required to justify management, especially on luss-accessible lands, where costs arc high.

Figure 6-3-Area of Forest and Nonforest Land by Region, 1987



NOTE: NE=Northeast, NC=North Central, SE=Southeast, SC=South Central, GP=Great Plains, RM=Rocky Mountain, PSW=Pacific Southwest, PNW=Pacific Northwest and Alaska. To convert acres to hectares, multiply by 0.405.

SOURCE: K.L. Waddell, D.D. Oswald, and D.S. Powell, *Forest Statistics of the United States, 1987,* Resource Bulletin PNW-RB-168 (Portland, OR: USDA, Forest Service, Pacific Northwest Research Station, 1989).

Table 6-I—Human Values Associated with Forest Systems

Products	Services
Wood	Recreation and tourism
Lumber	Biological diversity
Structural panels	Genes
Paper	Species
Fuel wood	Communities
Mulch	Wildlife habitat
Wildlife (game)	Landscape diversity
Water (quality and quantity)	Amenity function
Forage (livestock)	Microclimatic amelioration
Other	Sound attenuation
Seeds	Visual attractiveness, screening
Edible nuts	
Syrup (sugar maple)	Runoff, erosion management
Chemicals (e.g., rayon)	Soil, nutrient conservation
Pharmaceuticals	Pollutant and carbon sequestration
Pesticides	

SOURCE: Office of Technology Assessment, 1993.

produce scrubby trees or a sparse cover that would not support active timber management. About 46 million acres of forestland is *reserved forestland (87).* Forests in this category, such as those in National Parks and Wilderness Reserves, are administratively or legally unavailable for timber management. There are almost 35 million acres of *reserved timberland,* productive forestland that would be classified as timberland if it were not reserved (111). The regional distribution of acreage in timberland, and other forestland is presented in figure 6-3. Much of the timberland is found in the moister eastern half of the country. The timberlands of the West are concentrated in the Pacific Coast and Rocky Mountain States. The less-productive forestland is found mostly in arid regions of the West and in interior Alaska

Forest Types

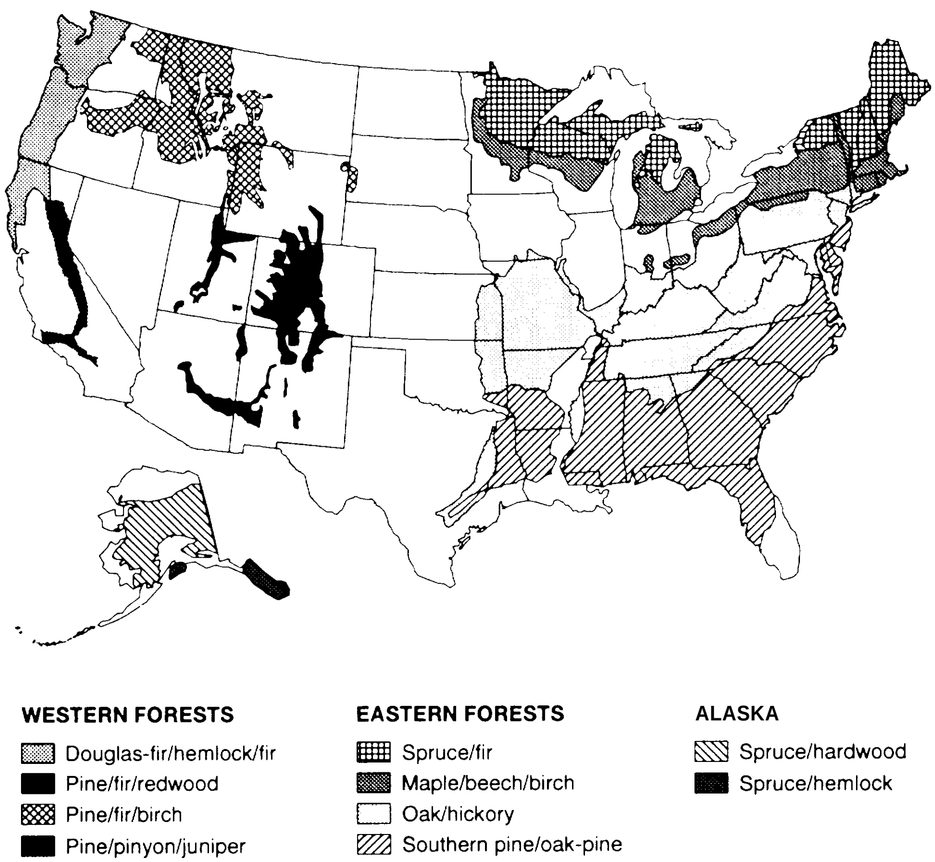
The Forest Service also classifies forests of similar character into *major forest types* (87). These types are most generally described as belonging to one of two broad classes: the *softwoods,* which include needle-leafed conifers such as the pines and firs, and the *hardwoods,* which are broadleafed trees such as oaks, hickories, and maples. In the East, most forests are a mixture of hardwood species, although large areas of softwoods are found in the southern and northern forests. The forests of the West are primarily softwood forests. The regional distribution of the major forest types is mapped in figure 6-4, and the distribution of timberland by forest type is detailed in table 6-2. A description of the major forest types of the United States can be found in box 6-A.

Timberland Ownership and Management

Nationwide, a little less than one-third of the total timberland is publicly owned.[6] Twenty percent of the timberland is on Federal lands, 8 percent is on other public (State and local) land,

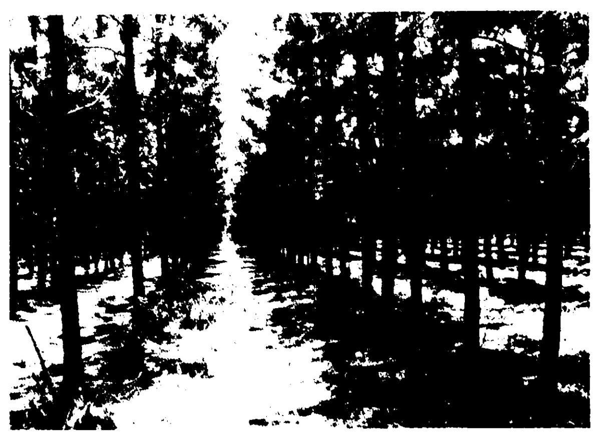
6 The public sector also holds about 75 percent of the 213 million acres of the forestland that is not productive enough to be considered timberland (1 11) and the 35 million acres of reserved timberland.

Figure 6-4-Major Forest Types of the United States



SOURCE: Office of Technology Assessment, 1993 adapted from J. Smith and D. Tirpack, *The Potential Effects of Global Climate Change on the United States* (Washington, DC: U.S. Environmental Protection Agency, 1989).

15 percent is owned by the timber industry, and 57 percent is held by other private landowners (fig. 6-5). The pattern of ownership varies across the country. In the East, most timberland is privately owned. In the West, much of the timberland is publicly owned. The distribution of timberland ownership by region is illustrated in figure 6-6.



A pine plantation forest in the Southeast. The United States is becoming increasingly dependent on the supply of timber from intensively managed loblolly pine forests of the South.

Private Timber *Industry Lands*

Timber industry lands (71 million acres) are generally highly productive sites and are actively managed to enhance timber productivity. There is a heavy concentration of timber industry lands in the loblolly pine forests of the South. Industry

Table 6-2—Area of Timberland in the United States by Major Forest Type, 1987 (in millions of acres)[a]

Eastern forest type	Area	Western forest type	Area
Softwood types		Softwood types	
Loblolly-shortleaf pine	49	Douglas-fir	33
Spruce-fir	17	Fir-spruce	27
Longleaf-slash pine	16	Ponderosa pine	25
White-red-jack pine	14	Lodgepole pine	12
Total	95	Hemlock-sitka spruce	11
		Larch	3
Hardwood types		Redwood	1
Oak-hickory	118	Other western softwoods	1
Maple-beech-birch	44	**Total**	112
Oak-pine	31		
Oak-gum-cypress	28	Western hardwoods	16
Aspen-birch	18		
Elm-ash-cottonwood	14	Nonstocked	2
Total	**253**		
Nonstocked	6		
Total, East	354	**Total, West**	**130**

[a] To convert acres to hectares, multiply by 0.405.

SOURCE: USDA, Forest Servce, *An Analysis of the Timber Situation in the United States: 1989-2040,* General Technical Report RM-199 (Fort Collins, CO: USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station, 1990).

Box 6-A-Major Forest Types of the United States

The eastern hardwood forests-The eastern hardwood types account for about half of the U.S. timberland and almost three-quarters of the eastern forest. Although many of these hardwood forests are harvested for wood products, they are rarely thinned, planted, or otherwise managed for timber production. Oak-hickory forests are the most widespread eastern forest type (see table 6-2), dominating in all but the more southern and northern areas. The acorns and hickory nuts area good food source for wildlife. Oak wood is valued for furniture and flooring. A limited market for the wood of the associated tree species and the difficulty in establishing oak plantations has limited timber management on this forestland. Mixed oak-pine forests are interspersed across the southern fringes of the oak-hickory forests. These forests, which often originate on cut-over pine sites, are attractive forests rich In wildiife and diversity. The maph-beech-birch forests of the Northeast and North Central regions are highly valued for their fall colors and for the sugar maple, yellow birch, and cherry wood that is desirable for furniture and specialty wood products. The oak-gum-cypress forest of the South, often associated with wildlife-rich wetlands and bottomlands, has been an important source of valuable hardwood timber. The aspen-birch forest is an early successional forest type in the North Central region that becomes established after fires and heavy logging. Aspen-birch stands revert to another type if left undisturbed. The development of technology that allows the use of aspen in waferboard structural panels has resulted in increased harvesting. The increased harvesting has slowed the loss of the aspen-birch forest type because the trees regenerate quickly after logging.

The eastern softwood forests-The eastern softwoods are the most important commercial timber forests of the East. Many of these softwood forests are under active management, with both planting and thinning taking place on the more productive lands. Recreational values of these forests for wildlife and hunting are also high. The *loblolly-shortleaf pine* forests of the Southeast and South Central regions are the most prevalent eastern pine ecosystem. The loblolly pine, especially, is the basis for a large and growing lumber and wood-fiber industry. The rapid growth oft he loblolly pine makes it t he preferred species for plantation forestry across the Coastal Plain and Piedmont regions of the South. Shortleaf pine can be found over a somewhat wider range than the loblolly, but it is now most prevalent outside the range where the loblolly is successful. Shortleaf pine is most concentrated in Arkansas, Texas, Mississippi, and Alabama.

Longleaf-slash pine forests are found mostly in Florida and southeastern Georgia. Slash pine is a commercially valuable species that occurs naturally on wetter sites protected from fires. It is widely planted and, as a result, its range is expanding, so it now dominates most of the longleaf-slash pine range. Longleaf pine stands were once found over much of the South. Logging and the control of wildfire (fire disturbance perpetuates the longleaf pine) led to the near eradication of the longleaf pine stands. Loblolly and shortleaf pines were often planted as replacements. The difficulty and high costs of artificial regeneration discouraged longleaf pine plantations. However, with better understanding of this attractive species it has recently made a comeback.

The *white-red-jack pine* and *spruce-fir* forests are found in the North. The spruce-fir forests are dominant in Maine and are also found across the northern areas of Michigan, Wisconsin, and Minnesota. They are an important source of fiber for pulpwood. Partly because of their remote location, they have also been a valuable recreational resource. The white-red-jack pine lands are scattered across New England, New York, and the northern areas of the Lake States. These were the primary timber forests of the early 1900s, but after heavy cutting and regrowth in hardwoods, relatively little remains of that softwood lumber industry. Although the northern lumber industry has declined, there is still some planting of red and white pine across the North.

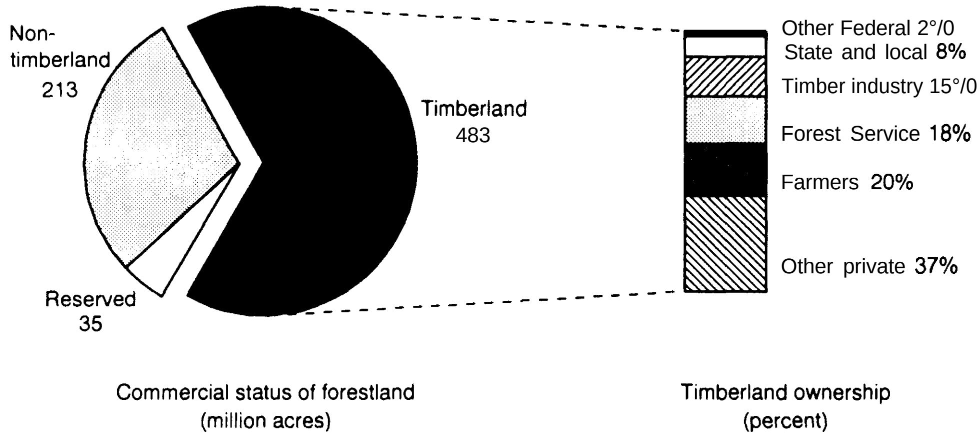
The western softwood forests—The western forests are primarily softwoods. *Ponderosa pine* forests are found throughout California, the Rocky Mountains, the Southwest, and east of the Cascades in the Pacific Northwest. In drier regions, ponderosa pine is usually the first forest ecosystem found above the desert floor. At higher elevations, ponderosa is replaced by Douglas-fir or other species requiring more moisture. The ponderosa pine forests are a major source of lumber. *Douglas-fir forests,* found in the Pacific Northwest and scattered throughout the ponderosa pine regions of the Rocky Mountains, are the most extensive western forest type. The Douglas-fir forests of the coastal slopes and Cascade Mountains of the Pacific Northwest are among the most productive of commercial forests. The wood is valuable for construction. The remaining old-growth stands of Douglas-fir are now also increasingly appreciated for thek recreational and aesthetic values.

Fir-spruce forests are found at medium to high elevation, generally above the Douglas-fir zone. These forest are becoming a significant source of wood products. Large areas of spruce forest (white and black spruce) are found in Alaska's interior. Few of these interior Alaskan forests are productive enough to be classified as timberland.

Other major western forest types include the *hemlock-sitka spruce forests* found in the moist fog belts near the coasts in Oregon, Washington, and Alaska, and the *lodgepole pine* forests found throughout the drier interior of the Pacific Northwest and the northern Rocky Mountains States. *Pinyon-juniper* forests are found extensively across the arid Southwest and *chaparral* lands are found across the Southwest, California, and Eastern Oregon. Despite the low productivity for timber (no land in these forest types is classified as timberland), these lands are increasingly valued for recreation, wildlife habitat, livestock grazing (especially after clearing to increase forage production), and as a source of fuel wood. The pinyon-juniper lands are also used for the commercial harvesting of pinyon nuts.

SOURCES: Office of Technology Assessment, 1993; USDA, Forest Service, An *Analysis of the Timber Situation in the United States; 1989-2040,* General Technical Report RM-199 (Fort Collins, CO: USDA Forest Service Rocky *Mountain* and *Range* Experiment, 1990).

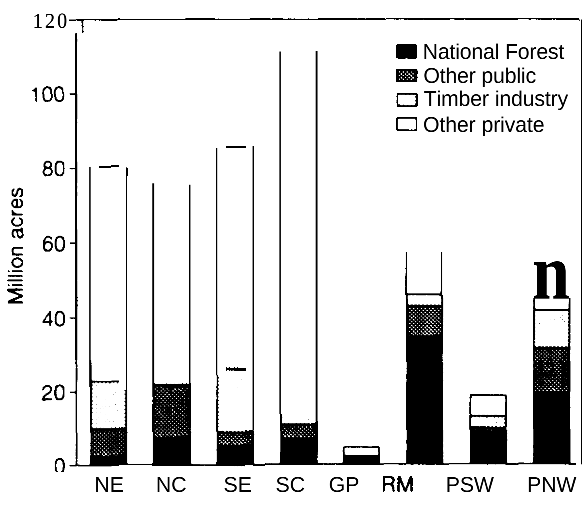
Figure 6-5-Status of U.S. Forestland and Distribution of Timberland Ownership, 1967



NOTE: To convert acres to hectares, multiply by 0.405.

SOURCE: K.L. Waddell, D.D. Oswald, and D.S. Powell, *Forest Statistics of the United States, 1987*, Resource Bulletin PNW-RB-168 (Portland, OR: USDA, Forest Service, Pacific Northwest Research Station, 1989).

Figure 6-6—Timberland Ownership by Region, 1967



NOTE: NE=Northeast, NC=North Central, SE=Southeast, SC=South Central, GP=Great Plains, RM=Rocky Mountain, PSW=Pacific Southwest, PNW=Pacific Northwest and Alaska. To convert acres to hectares, multiply by 0.405.

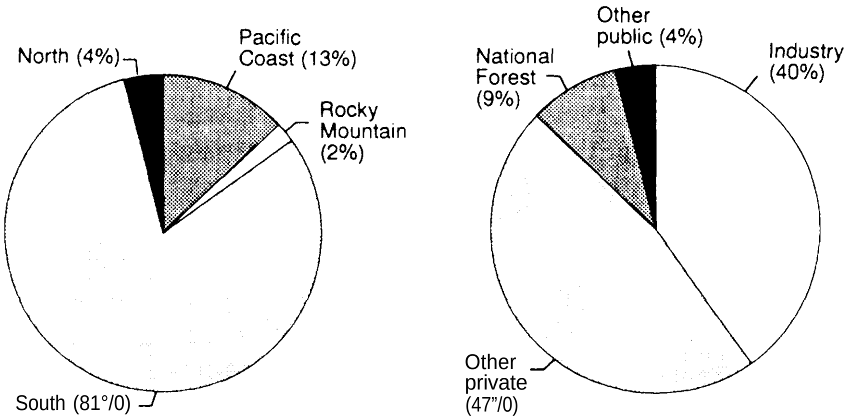
SOURCE: K.L. Waddell, D.D. Oswald, and D.S. Powell, *Forest Statistics of the United States, 1987*, Resource Bulletin PNW-RB-168 (Portland, OR: USDA, Forest Service, Pacific Northwest Research Station, 1989).

holdings in the softwood forests of the Northeast, the Lake States, and Pacific Coast States are also significant. About 30 percent of the Nation's commercial timber harvest comes from timber industry lands (90). In 1988, the timber industry planted almost 1.4 million acres of forestland (see fig. 6-7), with most of the planted acreage in the South (88). Intermediate management activities, typically thinnings, occurred on about 0.8 million acres of industry land in 1988, again primarily on forestland in the South (88). The seemingly small area where industry thinning or planting occurs equals about half of the total forest acreage where such active management takes place (88).

Farmer-Owned and Other Private Lands

Some 276 million acres of timberland are held by nonindustrial private landowners, that is, owners whose primary business is not the manufacture of wood products. Farmers are the largest identifiable subgroup of these landowners. Holdings are concentrated in the East. Although timber management is often not the primary motivation

Figure S-7-Forest Area Planted or Seeded In the United States by Section and by Ownership



SOURCE: U.S. Department of Agriculture, Forest Service, *FY 1988, U.S. Forest Service Planting Report, Planting, Seeding and Silvicultural Treatments in the United* States (Washington, DC: USDA, Forest Service, 1989).

for ownership, this private forestland is an important source of wood products, accounting for almost half of the Nation's timber harvest volume. In 1988, tree planting on nonindustry private lands accounted for only 0.5 percent of the total acreage planted. Planting acreage on the nonindustry lands has risen since the early 1980s because of the implementation of various Federal and cooperative programs intended to encourage investments in forestry. These programs are discussed in more detail later. Reforestation on private lands is now considered an important way to sequester carbon that might otherwise add to atmospheric carbon dioxide (CO_2) concentrations (box 6-B).

National Forest Lands

The National Forest System, managed by U.S. Department of Agriculture's Forest Service (USFS), includes some 191 million acres of land. Roughly 142 million acres are forested (87), and 85 million acres of that are classified as timberland (111). The National Forest holdings make up by far the largest share of the publicly owned timberland, and comprise almost 18 percent of U.S. timberland. The forested acreage not considered timberland includes wilderness reserves along with a larger area of low-productivity forestland. Much of the National Forest land is in the West. Typically, this land remained in public hands because of its inaccessibility or unsuitability for settlement. National Forest lands in general tend to be less productive and more costly to harvest than the average private timberlands. Low productivity, poor access, and the desire to provide services other than timber production limit the National Forest land available for timber harvest to about 57 million acres. Still, because these forests now contain roughly 40 percent (by volume) of the Nation's harvestable softwood timber, they are an important potential source of timber supply. The National Forests now supply about 13 percent of the Nation's timber harvest

Management intensity varies across the National Forest lands. Except for the management of wilderness lands, National Forest management must reflect a concern for the multiple uses-for timber, recreation, wildlife, rangeland, and watershed-and for the long-run sustainability of the forest. The Forest Service also manages 37 million acres of wilderness reserves, has habitat-management responsibility for over 30 percent of

Box 6-B-Forests and Carbon Sequestration

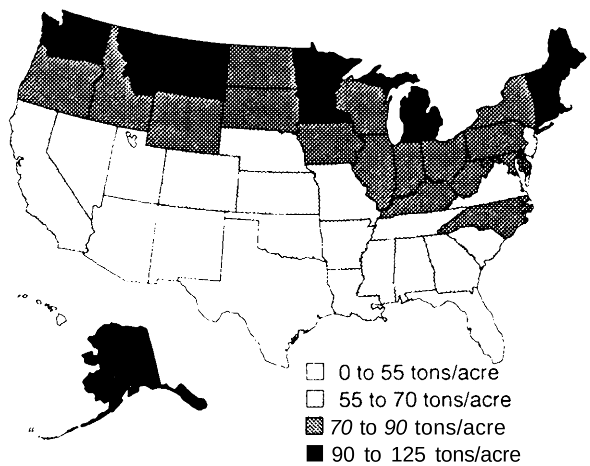
Climate change can affect forest growth and distribution; forests, in turn, can affect climate change because they store and release carbon. Carbon dioxide (CO_2) is the major greenhouse gas accountable for more than half of the projected warming. The 731 million acres (246 million hectares) of U.S. forests serve both as a source of CO_2 emissions (when harvested, burned, or decaying) and as a sink for CO_2 absorption (while growing). Reduction of atmospheric CO_2 can be achieved through a reduction in fossil fuel use or through CO_2 emission offsets (that is, measures that effectively remove some emissions from the atmosphere). Forestry offers one avenue for temporary CO_2 emission offsets, and it is being actively considered as part of the U.S. strategy to meeting international obligations under the Climate Convention. On Earth Day 1993, President Clinton pledged to freeze greenhouse gas at 1990 levels by the year 2000, as many industrializing countries had already done at the 1992 Earth Summit in Rio de Janeiro.

The *rate* at which trees take up or sequester carbon is directly related to growth; the *total amount of* carbon in a tree depends on size or total biomass. Old-growth forests contain large amounts of carbon (over 240 tons per acre[1] in some areas of the Pacific Northwest) but exhibit little or no net growth or additional carbon storage (83). Second growth forests contain less carbon, but continue to take up and store carbon. Plantations with rotation periods of 50, 75, and 100 years result in storage of 38,44, and 51 percent, respectively, of thecarbonthat an old-growth forest stores (24).

A comparison of accumulation and release of CO_2 shows that U.S. forest trees currently store 117 million tons of carbon per year more than they release. For comparison, this is equivalent to about 9 percent of the annual U.S. emissions of carbon to the atmosphere from all sources (96).

For the United States, OTAestimatesthat with massive planting and management efforts, trees could offset another 2 percent of U.S. CO_2 emissions (26 million tons) by the year 2000. By 2015, this uptake of CO_2 could triple (83). The uptake of carbon by forests can be increased by managing forests more intensively, increasing the forest-covered area, restricting some commercial harvests, and increasing efficiency in the manufacture of forest products.[2] More-intensive management practices include increasing the site preparation (through drainage and some fertilization), using genetic manipulation and selecting particular strains, using improved nursery practices, and using techniques to protect from fire, insects, and disease.

Average Carbon Storage per Acre of Forestland in the United States



NOTE: Numbers Include carbon stored In soil, forest floor, understory vegetation, and both live and dead trees. Northern forests tend to be older than southern forest and therefore store more carbon. Also, carbon storage In the forest floor Is higher In cooler, wetter climates.

SOURCE: U.S. Department of Agriculture (USDA), Forest Service, *Carbon Storage and Accumulation in United States Forest Ecosystems,* **General Technical Report WO-59 (Washington, DC: USDA Forest Service, August 1992).**

[1] 600 tons per hectare. To convert acres to hectares, multiply by 0.405.

2 This assumed doubling the enrollment of Conservation Reserve Program lands by 1995; increased productivity on one-third of nonindustry lands; improved productivity on two-thirds of industry lands; general afforestation of another 70 million acres; and planting 1 million acres of biomass crops.

Increased forest cover can be accomplished through **afforestation,** reforestation, and urban planting. **Afforestation—planting** trees on land that has never supported forests or where forests have been cleared for decades-offers opportunities to store carbon and help stabilize soil. Reforestation-planting trees on land that has recently been deared **of trees—can** be encouraged by incentive programs such as the Conservation Reserve Program (CRP), which aims to plant trees on 6 million acres of **cropland.** Urban planting can help to reduce the "heat **island"** effect common in cities and can reduce the need for air conditioning.

There are several caveats **to using** trees **to offset** CO_2 **emissions.** C**abon will** eventually be released **to the** atmosphere either when trees die and decompose, when they are **harvest**ed or burned, or when products made from them decompose. Unless wood is used **to displace fossil** fuels or is permanently stored under conditions that do not allow decomposition, carbon offsets in later years will dwindle. The average **forest**[3] in the United **States** holds approximately 60 tons of organic carbon per acre. However, the quantity of carbon sequestered, or stored, varies considerably by forest type and region. Douglas-fir forests and Spruce-fir forests hold roughly 100 tons of carbon per acre, whereas **Pinyon-juniper** forests and **loblolly** pine forests hold around 40 to 75 tons of carbon per acre respectively (96)[4]. Forests in the Pacific Coast States store approximately 100 tons of carbon per acre (40 percent of the total carbon stored in U.S. forest ecosystems) (96). Forests in the South Central States store approximately 60 tons of carbon per acre (10 percent of the total carbon stored in U.S. forest ecosystems) (96). Soil stores the largest portion of carbon in U.S. forest ecosystems, 50 percent (29 billion tons).

If timber harvests are restricted to avoid releasing CO_2 and to store carbon, alternatives to wood products would have to be found to meet an increasing demand for wood and paper products. Small-scale restrictions, such as restrictions on harvesting old-growth forests, will not have a large effect on CO_2 emissions; however, this action can be justified for a variety of other reasons such as the preservation of **biodiversity** and virgin forests.

Forestry options designed to reduce or offset CO_2 emissions in the United States cannot be considered a substitute for reducing **total** energy use or for developing alternatives to fossil fuel. However, they can be used as an avenue to ease the transition to developing alternative sources and improving the **eff iciency** of energy use in general.

3 Forests refer@ **soil, forest floor, and trees.**

4 **The average annual carbon storage rate for all U.S. timberland was 0.3 metric tons carbon per acre; potentially, fully Stocked forests could average about 0.6 metric tons carbon per acre. Under experimental conditions, genetically improved loblolly pine achieved 1.2 metric tons carbon per acre over a 35-year period.**

SOURCE: Office of Technology Assessment, 1993.

the Nation's threatened and endangered species of plant and animals, and attracts a growing number of visitors who participate in recreational activities (89). (Box 6-C **summariz**es the major Federal laws that regulate forest management.) National Forest lands account for about 9 percent of total acreage of forest that is replanted in the United States and about 25 percent of the forest acreage that is **thinned.**[7]

Other Public Lands

Other public timberland accounts for about 11 percent of U.S. timberland. This includes 5.4 million acres of the Federal public lands held by the U.S. Department of the Interior's Bureau of Land Management **(BLM)** and acreage administered by the Bureau **of** Indian Affairs and the Defense Department, along with a much larger area of State and local timberland. The greatest

7 **In 1990,** 215,000 **acres** of National Forest lands were planted or reseeded, while 140,000 acres were **allowed to regenerate naturally after** harvesting (94). In the same year, 190,000 acres (less than **1/500th of** the Forest **Service forested acreage) received some intermediate treatment, mostly thinning to remove lower-valued timber and to improve the growth of the remaining trees.**

Box 6-C-Major Federal Laws Related to Forest Management

The Multiple-Use and Sustained-Yield Act of 1960-The Multiple-Use and Sustained-Yield Act (MUSY; P.L 86-517) provided formal statutory authority to the Forest Service for managing the National Forests for outdoor recreation, range, timber, watershed, and wildlife. The authority to manage for these "multiple uses" supplemented the Forest Service's original charge, provided by the Forest Service Organic Act of 1897, to furnish a continuous supply of timber and to secure water flows. MUSY does not setup any new management system or provide a planning structure, but it is the legal foundation for the concepts of balancing use and preservation. Despite the lack of management direction, the MUSY philosophy continues to be the cornerstone of both Forest Service and Bureau of Land Management practices, affecting a total of some 460 million acres (190 million hectares)[1] in the United States (81).

The National Environmental Policy Act of 1969-The National Environmental Policy Act (NEPA; P.L. 91-190) responded to a growing concern that Federal agencies were placing excessive emphasis on economic values over environmental values. This act represents a major divergence from the traditional focus on economic gain by suggesting that environmental goals might outweigh economic gain in some cases. NEPA mandates certain decision making procedures and requires public participation in major Federal activities to ensure that environmental values are given appropriate consideration in decisionmaking. The environmental impact statement (EIS) required for Federal activies that "significantly affect? the human environment must include the identification of adverse environmental effects, alternatives to minimize adverse impacts, and short-and long-term ramifications of the proposed project, and it must be made available to the public for comment.

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) as amended by the National Forest Management Act of 1976 (NFMA)-These two laws taken together specify and direct Forest Service management and planning activities. Enactment of RPA (P.L. 93-378) and NFMA (P.L. 94-588) stems from: 1) concern over adverse environmental impacts on forest resources in the 1970s, 2) the lack of specific direction in MUSY and 3) NEPA's mandate that all agencies use a systematic approach in their decisionmaking processes. Whereas RPA sets goals, objectives, and planning strategies at the national level, NFMA directs forest planning at the local level, closely following the EIS process. Together, RPA and NFMA allow for a top-down and bottom-up approach to National Forest planning. Goals and objectives are set out at the national level under RPA, while the actual balancing of various resource uses is generally left to the National Forest manager under NFMA. The acts represent a comprehensive and relatively specific planning directive for the Forest Service based on the principles of multiple use and sustained yield.

RPA is based on the assertion that the "renewable resource program must be based on a comprehensive assessment of present and anticipated uses, demand for, and supply of renewable resources from the Nation's public and private forests and range lands, through analysis of environmental and economic impacts, coordination of rnultiple use and sustained yield opportunities." Four documents are required periodically: an Assessment a National Program, a Presidential Statement of Policy, and an Annual Report.

The RPA Assessment which is updated every 10 years and considers a 50-year planning horizon, contains an analysis of expected uses and price trends, an inventory of all renewable resources, and an outline and description of Forest service responsibilities and other policy considerations (e.g., laws and regulations). The RPA Program which is updated every 5 years with a 50-year planning horizon, contains a listof needs and opportunities in National Forest management and identifies benefits and costs. The Presidential Statement of Policy is used to frame budget requests when the RPA Program is sent forward. By enacting this provision, Congress sought to retain and assert control over the Forest Service budget by specifying its ability to disapprove and revise the policy statement. The Annual Report is intended to evaluate the effectiveness of the program. Specifically, it provides

1 To convert acres to hectares, multiply by 0.405.

information to assist Congress in its oversight responsibilities, requiring the Forest Service to account for expenditures and to evaluate progress in implementing the RPA Program.

The National Forest Management Act directs the Forest Service to produce long-term, integrated forest plans for each National Forest unit at least every 15 years, with updates as needed. NFMA directs the Forest Service to set substantive standards and guidelines for timber management and protection of water and other renewable resources. Some provisions of NFMA are very specific to harvest practices and reflect a concern that the Forest Service's timber-harvesting methods were degrading the environment unreasonably. NFMA also provides for extensive public involvement in Forest Service planning processes.

The Federal Land Policy and Management Act of 197&The Federal Land Policy and Management Act (FLPMA; P.L. 94-579) established the Bureau of Land Management (BLM) as a permanent agency and claimed permanent Federal ownership of 270 million acres of public lands, primarily in the West and Alaska. FLPMA sets goals for BLM, prescribes a planning process, and allows for public involvement. Under the provision of FLPMA, the public lands are managed in a manner that protects the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archaeological values; that provides food and habitat for fish and wildlife and domestic animals; that provides outdoor recreation; and that recognizes the Nation's need for domestic sources of minerals, food, timber and fiber.[2] Clearly, BLM is charged with balancing a wide variety of values.

FLPMA requires BLM to prepare Resource Management Plans for each region. These plans, prepared with a 15-year planning horizon, must reflect the multiple-use and sustained-yield principle. In practice, a benefit-cost analysis is required before any implementation project begins. FLPMA requires that the public be allowed an opportunity to participate in the planning process and that BLM conduct an inventory of its resources. Further, FLPMA does not give any timetables or deadlines for completed plans and does not require that they be regularly updated. However, it does set up provisions for some management of BLM land.

The Wilderness Act of 1964-The stated purpose of the Wilderness Act (P.L. 66-577) is to provide for the protection of the wilderness resource in such a manner that it is left unimpaired for future use and enjoyment and that the preservation of its wilderness character is ensured. The Forest Service, the Fish and wildlife Service, the National Park Service, and, later, the Bureau of Land Management were required to study their lands and submit appropriate tracts to Congress for admission into the Wilderness Preservation System (areas already designated as wild or primitive were automatically included). Administration of t he Wilderness Preservation System, currently at 92 million acres, is the continued responsibility of the land-management agency that applied for admission. Each agency determines for itself what is appropriate management of the wilderness lands, consistent with the directions given by the act. This act does give more explicit guidelines than MUSYA. In general, it prohibits timber harvesting and motorized access, thus severely limiting active management in wilderness areas.

The Endangered Species Act of 1973-The endangered species legislation, as amended (P.L. 100-707), is the most restrictive and binding of all preserve laws. The purpose of the Endangered Species Act (ESA) is to conserve the ecosystems on which endangered species and threatened species depend. A species is considered endangered if it is in danger of extinction throughout all or a significant portion of its range, or *threatened* if it is likely to become endangered in the foreseeable future. A species is listed as endangered or threatened based solely on scientific evidence, without regard to the costs of protection. Federal agencies are then required to ensure that their actions do not jeopardize the continued existence of these species. Once a species is listed, it is unlawful to harm, capture, or kill it. The Secretary of the Interior may designate critical habitat for the species—an area in which both private and public activity is restricted-after taking into consideration the scientific evidence and the potential economic impact.

[2] 43 U.S. Code (U. S. C.) 1701(8).

(Continued on next page)

Box 6-C-Major Federal Laws Related to Forest Management--(Continued)

In Oregon, California, and Washington, the ESA has led to heated conflicts between logging communities and proponents of protection for the northern spotted owl. The spotted owl, which nests in valuable forests of the Pacific Northwest, is listed as endangered. Logging activities in many areas have been halted by claims that further logging would cause extinction. If the restrictions on logging are upheld, some 5,000 or more jobs maybe at stake (17).

The National Park Service Organic Act of 191&This act (P.L. 85-434) spells out the goals of the National Park System, administered by the National Park Service (NPS) of the Department of Interior. The general mission is to conserve the scenery, wildlife, and natural and historic objects within the parks, managing the parks to provide for public enjoyment and to leave them unimpaired for future generations. This directive sets up a dual mission for NPS to conserve and preserve the values in the parks and to provide for public enjoyment. Specific goals and purposes for each National Park unit are specified in its establishing legislation and management documents.

The National Parks and Recreation Act of 1978—Planning has evolved in the National Parks since the 1960s to allow for zoning within park boundaries to protect pristine areas and allow greater development and management in other specified areas. The National Parks and Recreation Act of 1978 (P.L. 95-625) required the preparation of general management plans for each unit of the National Park System. Generally, three documents are prepared. The Statement for Management, prepared by the park superintendent and updated every 2 years, provides a concise description of the park's purpose and current management practices. The General Management Plan sets forth the basic philosophy for the park and provides strategies to meet the issues and objectives (specified in the Statement for Management) within a 5-to 10-year time frame. Finally, the Outline of Planning Requirements, prepared by an interdisciplinary team, is an analysis of the plans and tasks that must be done to address the issues and objectives (105).

The Clean Air Act of 1970 (as amended in 1977 and 1990)--The purpose of the Clean Air Act (P.L. 91-604) is to promote and enhance the quality of the Nation's air resources in order to protect public health and welfare. Generally, the act sets two types of National Air Quality Standards, primary and secondary. Primary standards are set to protect human health, and secondary standards seek to protect public welfare.[3] Prescribed burns on forestland can be limited by the need to comply with the requirements of the Clean Air Act.

The Clean Water Act of 1972 (as amended in 1977,1981, and 1987)—The goal of the Clean Water Act (P.L. 92-500) is to restore and maintain the chemical, physical, and biological integrity of the Nation's water. The 1987 amendments to the act encourage "best management practices" (BMPs) to control non-point-source pollution. Best management practices required to control soil erosion will often restrict the nature of harvesting activity allowed within stream zones. Section 404 of the act is a regulatory mechanism for wetland protection, restricting the draining or filling of wetlands. Standard forestry activities are exempted from the permitting requirements of Section 404, allowing temporary drainage during harvesting and planting. Activity by a forestland owner that would permanently alter wetlands, through drainage or filling, may be restricted.

[3] Secondary standards generally seek to protect all aspects of the human and natural environment except for human health and may include protection for soil, water, crops, vegetation, materials, animals, wildlife, weather, visibility, climate, transportation hazards, and personal comfort (45).

SOURCE: Office of Technology Assessment, 1993.

concentrations of these other public timberlands are in the North and in the Pacific Northwest States. Again, the intensity of management varies, but multiple-use management is usually allowed. Much of the other Federal forestland is not counted as timberland; this other land includes forests in the National Park System (see ch. 5), wilderness reserves (variously administered by the National Park Service, BLM, and the Forest Service), other reserves, such as those administered by the Fish and Wildlife Service, and large areas of unproductive forestland (many held by BLM and the Forest Service).

Trends in the Forest Resource

Much of the loss of the Nation's original forestland occurred when colonists settled the various regions of the United States. The decline in the forest resource slowed in about 1920, which marked the end of a period of heavy logging and conversion of forestland to agriculture (20, 73). Since the 1920s, the general trend has been toward a gradual increase in forest acreage, with much of that increase resulting from the reversion of eastern farmland to forests. More recently, there has been some loss in forest acreage, particularly during the 1970s, when growing export demands for agricultural products led to the conversion of forestland to agriculture. This conversion seems to have ended, and projections suggest some cropland acreage will likely revert to forest cover (100) (see vol. 1, ch. 6). Conversion of forest to residential and commercial use may result in some future loss in forestland. However, the rate of loss is expected to be modest, with forestland projected to decline from 731 million acres in 1987 to about 710 million acres by 2020(87). The condition of forestland, as measured by the volume of standing timber, has greatly improved since the 1920s—with the maturing of forests on previously cleared or degraded lands. Despite the reduction in forest area in recent years, the volume of timber increased by 24 percent from 1952 to 1987 (111).

Other trends are cause for concern. Much of the loss of forestland has been regionally concentrated. For example, in the South, agricultural conversion and urbanization rates have been high. Perhaps more significant than the overall forest acreage loss has been the great reduction in the area of some natural forest types. For example, the longleaf pine forests of the Southeast have been essentially lost due to past logging; to fire suppression, which changed the natural forest ecology; and to the planting of loblolly and shortleaf pines. The bottomland hardwood forests of the lower Mississippi valley have been extensively cleared and converted to agriculture (see box 6-D). This large-scale conversion of bottomland forests, however, is not expected to continue because of wetland-conservation efforts (see ch. 4), the lack of adequate drainage on remaining lands, and the declining demand for agricultural land (70).[8] In the Pacific Northwest, the extensive old-growth Douglas-fir forests have been greatly depleted. This trend also appears to have been slowed by efforts to preserve the habitat of the spotted owl, which is protected under the Endangered Species Act (P.L. 100-707).

More generally, and particularly in the East, forest holdings have become fragmented by urban development and agricultural conversion. Landscape fragmentation may complicate tree migration or lead to the elimination of local populations, thus threatening the genetic diversity of the Nation's forests (see chs. 3 and 5).

Of additional concern are diverse natural and human threats to forests on a regional scale. overall timber mortality is now relatively low, with annual losses less than 1 percent for established trees (111). For the most part, the loss is widely scattered and not easily attributed to a specific cause. However, there are cases of regional forest decline, caused either by unusual climatic conditions or by people. Recent ex-

SW. Jarck, Corporate Director, Forest Resources, Georgia-Pacific, personal communication, June 1993.

Box 6-D-Southern Bottomland Hardwoods: Converting Wetland Forests to Agriculture

The Mississippi Delta is home to the largest contiguous wetland in the lower 48 States. Southern bottomland hardwood forests cover 5.2 million acres (2.2 million hectares)[1] along the waterways of this delta wetland region, including areas of Louisiana, Mississippi, and Alabama. These southern bottomland hardwood (SBH) forests host a variety of tree species that are of high economic value for forestry. They also play a vita! role in flood prevention, in erosion control, and as flyways and habitat for millions of migratory birds. To date, 80 percent of this once vast system of forested wetlands has been lost (18). Past Federal flood-control and drainage projects in the Delta led to the clearing, draining, leveling, and conversion of large parcels of SBH to agricultural use (1 04). These activities created the potential for irreversible damage to the entire wetland system. Global climate change promises to place the system under further stress.

The cumulative impacts of small changes in the SBH of the Delta can have wide-ranging effects on species, hydrologic function, soil erosion, and water quality. The hardwood reserve is home to a multitude of deciduous species (cottonwood, cypress, tupelo, sycamore, red@ green ash, sugarberry, and sweetgum). The hardwood timber industry of the southern United States depends on these productive forests as a source of high-quality wood products and pulpwood supplies. The underbrush provides essential habitat for a variety of waterfowl (e.g., wood duck, pintail, teal, and black duck). A host of geese, diving ducks, and migratory songbirds relies on this ecosystem for a wintering and nesting area. In addition, an active hunting economy is supported by the plethora of squirrels, white-tailed deer, and wild turkey that make their home in these bottomland communities. These systems are dependent on fluctuations in water level to maintain their high productivity, and altering the SBH ecosystem, by disturbing the hydrology, alters the forest vegetation and soils and ultimately can leave the land incapable of handling high flood peaks and large storm events. Such flood-control functions and values are difficult to quantify, but as the Mississippi floods of 1993 demonstrated, they are essential to maintain. (See box 4-D for a discussion of wetland values.)

Federal flood-control and drainage projects common in the Delta during the 1930s resulted in levees, floodways, channelization, and tributary basin modifications. These projects, while providing flood protection for nearly 20 million acres of land in the Delta, also paved the way for agricultural conversion in the bottomlands. The advent of these projects made agriculture not only technically feasible but economically attractive. In addition, the Federal Government created myriad farm programs that further supported conversion and promoted agricultural use. These farm programs came in the form of production subsidies, technical assistance, and support for the expansion of exports. Flood-control and drainage projects, farm programs, and periods of high agricultural prices were together the causes of most of the wettand forest depletion from 1935 to 1984 (see ch. 4, figs. 4-3 and 4-4, for illustrations of wetland losses).

With an end to the Federal drainage projects, a decline in the markets for agricultural products, a strong market for higher-quality hardwoods, and growing interest in the protection of wetlands, there has been a slowdown or reversal in the conversion of the SBH forest to agriculture over the past decade. The new economic realities have brought agricultural conversion to a virtual halt. Instead, there has been increased investment in restoring once-forested wetland and in managing the forest resource on those still intact.[2] Some of these reconversion efforts are being championed and even subsidized by members of the timber industry who have significant economic interests in maintaining southern timber reserves. Small landowners are turning to the timber industry for support in these projects, with ecological restoration of lost forest acreage as a long-term goal. The silvicultural activity is generally not incompatible with maintaining the wetland services of the lands. Indeed, relatively high values for hardwood forest products and other economic incentives for hardwood forest

1 To convert acres to hectares, multiply by 0.405.

2 R. Olezsewski, Georgia-Pacific Corporation, personal communication, July 1993.

management should help promote the continued conservation of wetlands. Global climate change may bring new physical stresses and changes to the nature of human demands on the bottomlands. Increases in temperatures, changes in precipitation, and altered hydrology of the wetland systems may change the economics of agricultural production and lead to disturbance and changes in forest composition. In addition, sea level rise might cause some inundation of coastal systems. Asa result, SBH could suffer from alterations in biodiversity influenced by changes in vegetative composition and soil characteristics and distribution (95). Collectively, these changes could change the future of agriculture and silviculture in the Delta region, increasing uncertainty about whether there will be continued maintenance of these valuable wetland forest resources.

SOURCES: A. Bartuska, U.S. Fish and WildlifService, personal communication, July 1993; Environmental Defense Fund (EDF) and the World Wildlife Fund (WWF), *How Wet Is a Wetland? The Impacts of the Proposed Revisions to the Federal Wetlands Delineation Manual* (New York NY and Washington, DC: EDF and WWF, 1992); U.S. Department of Agriculture (USDA), Forest Service, *Research Needs Associated with Global Change Impacts on Southern Forested Wetlands*, Summary of a Workshop Convened by the Consortium for Research on Southern Forest Wetlands, Feb. 13-14,1991, Baton Rouge, LA (Washington, DC: USDA, April 1991); U.S. Department of the Interior, *The Impact of Federal Programs, Volume 1: The Lower Mississippi Alluvial Plain and the Prairie Pothole Region*, a report to Congress by the Secretary of the Interior, October 19SS; U.S. Department of the Interior, Fish and Wildlife Service, "Synopsis of Wetland Functions and Values: Bottomland Hardwoods with Special Emphasis on Eastern Texas and Oklahoma," *Biological Report*, vol. 87, No. 12, September 1987.

tended droughts in California and in many interior areas of the West (particularly eastern Oregon and Idaho) have been a major factor in locally very high rates of insect infestation, fire, and forest mortality (see box 6-E). Excessive fire suppression and selective harvesting of drought-tolerant ponderosa pines in the past may have increased the forest's vulnerability to drought and disease (92). Airborne pollution is implicated in the death of high-elevation red spruce in the Northeast and in the decline in the growth of pines in the Southeast (87). Ozone and smog are implicated in damage to forests near urban areas, such as those of Southern California (82). Acid rain and heavy metals may eventually alter forest soils and have some cumulative effects on forest productivity. Acidic deposition and management activities are suspected causes of the apparent sugar maple decline in the northeastern United States (76).

One of the striking trends in forestry over the past 70 years has been the reduction in forest acreage burned by wildfire (20, 94). Until 1945, forest fires often burned over 30 million acres annually. Individual catastrophic frees in the West have at times burned more than a million acres of forestland (20). Since the early 1950s, however, the annual acreage burned has never exceeded 10 million acres and is usually below 5 million acres. This reduction in loss to fire has resulted from changes in private land-management practices (less brush burning for pasture clearing, fewer sparks from logging equipment, and less arson), better access and equipment for fire suppression, and increased State and Federal fire-suppression efforts. The droughts of the late 1980s did lead to an increase in the number of fires and the acreage burned, but not to levels that were high by past standards (fig. 6-8).

Trends in Forest Management

Over the course of the past few decades, the perception of the value of forests has changed among scientists and the public, and so has the acceptability of certain forest-management practices. Scientists have learned more about the complexity of forest ecosystems and about how overall productivity of forests can be damaged in ways that had not been anticipated. Together, these changing public and scientific perceptions are altering the manner in which allforestland can be managed.

The decades after World War II were a period of rapid growth in the use of the public forestland, with increases in both timber harvests and recrea-

Box 6-E–The Blue Mountains: Forest Decline and Climate Change

If climate change leads to hotter and drier conditions in the West, forests will become more vulnerable to drought stress, disease, and infestations. Increased mortality rates could lead to rapid fuel buildup and increase the risk of intense, widespread wildfire. In many parts of the West, the impacts of drought stress on forests are already well-known. The 7 years of drought in the West coupled with over 100 years of fire suppression transformed many western forests from healthy, robust stands to weakened, overcrowded, and disease-ridden tinderboxes. These conditions exist today without the added impacts of climate change. Because a drier climate in the West can only exacerbate drought stress, an examination of this situation may give some dues about the complicated nature of future climate impacts in other forested areas.

The forests of the Blue Mountains in Oregon are facing the most severe and widespread effects of drought and drought-induced disease. In 1850, this region was characterized by stands of mature pine and western larch, large grassy openings, and lack of underbrush. Frequent fires were a critical part of preventing overcrowding and of stemming disease spread. A series of droughts and intense logging of the valuable pines in this area around the turn of the century set the stage for a new generation of trees. Fire suppression allowed shade-tolerant fir species to sprout and fill areas where the pines had been logged. Because new sprouts and weak trees were not eliminated by fire, the stands have become dense. Furthermore, fir species are generally less disease- and fire-resistant than the pines they are replacing. Although disease has plagued the forests of the Blue Mountains many times this century, the most recent outbreak, fueled by the continuing drought, poses grave threats to local communities, industry, wildlife, and the ecosystem.

Drought impacts-in 1990,53 percent of three National Forests in the Blue Mountains contained dead or insect-defoliated trees. Over 20 types of insects and diseases, including the Douglas-fir tussock moth and the western spruce budworm, were identified as causing forest mortality. In 1992, the Palmer drought index showed the area under extreme drought conditions (triple the size of 1991), "covering nearly all of the western forests" (48). Conditions were ripe for catastrophic fires that could destroy homes and communities. However, drought is not the only threat to forest resources in the Blue Mountains. The upper Grand Ronde River that runs through the Blue Mountains has lost 70 percent of its salmon pool habitat in the past 45 years due to road building and logging. Salmon fishing is an integral part of Indian tradition in this area, but many have been unable to pass it on to their children because the fish populations have gotten so low. Logging in this area has created a fragmented landscape, with more wildlife habitat at the vulnerable fringes.

Fragmentation and risk allocation-Although most agree that there isaseriousforest-health problem and fire risk in the Blue Mountains, it is less clear what the solutions are. These Blue Mountain problems transcend ownership and management boundaries. Three National Forests with up to 25 different management areas, six towns, several Indian reservations, several private forests, and a smattering of private homes are intertwined in the Blue Mountains. Any management decision for the Blue Mountain forests will affect all of these parties, and even if ecologically sound, it may be met with resistance by inhabitants and communities that depend on the forests for their economic base.

One suggested solution includes the use of fire to reduce fuel loads and prevent the disease spread. However, this poses a risk to small communities and homes that are nestled within forested lands. In addition, Clean Air Act provisions restrict fire use because of particulate pollution. In many places, the risk that prescribed fire would burn out of control is very great, and the fuel buildup is so dense that any such fire would be extremely hot and would destroy soil nutrients, turn day soils to brick, and cause massive erosion and environmental damage.

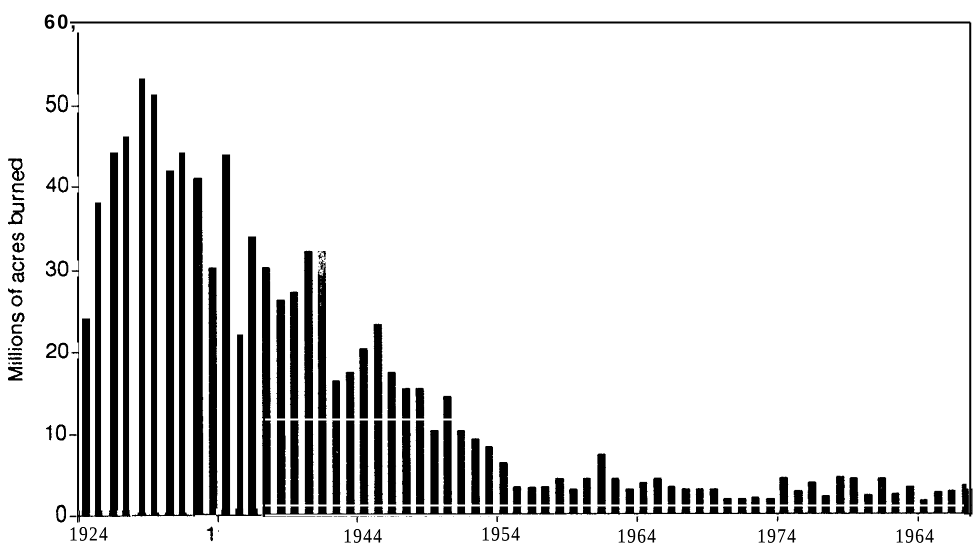
Salvage harvests are another proposed solution supported by the timber and forest products industries. Diseased timber is only good for commercial use up to 2 years after it dies. Salvage harvests would "salvage" some of this revenue, reduce fuel loads, and provide local jobs. In addition, the thinned stands would enhance the remaining trees by removing the competition for soils, moisture, and nutrients. However, this measure is not supported by environmental groups, who seethe widespread use of salvage harvests as a ploy to build roads into roadless wilderness areas, accelerate logging, promote dear-cutting, and avoid environmental considerations and public participation. Dead trees also provide valuable shelter for wildlife species that reside in these forests.

Climate change may only add to these drought problems, and there is little agreement over how to best move toward solutions. Nevertheless, it is apparent to land managers and experts in the Blue Mountains that simply treating the symptoms is not an adequate strategy. Efforts to move to an ecosystem or landscape approach that focuses on biodiversity, watershed health, the natural rde of fire, and long-term site productivity can slowly restore the forest to a healthy system.

SOURCES: H.E. McLean, "The Blue Mountains: Forest Out of Control," *American* Forests, September/October 1992, pp. 32-35, 5S, 61; USDA, Forest Service, Blue Mountains Forest Health Report, *New* Perspective/n *Forest Health* (Portland, OR: USDA, Forest Service, Pacific Northwest Region, April 1991).

tional use. The resulting conflicts over appropriate use of public forestland have not yet been resolved-despite efforts to formalize the forest-planning process and open it to public scrutiny (9). In fact, there has been a rising sentiment that timber management may be leading to the degradation of forest ecosystems (21, 63). This perception has been reflected in a trend toward more-restrictive legislation and regulation of forest practices (box 6-C). Clearcutting of forests and artificial regeneration (i.e., planting of seedlings) are increasingly viewed as controversial and perhaps unacceptable forest practices. Even private landowners are finding that their forestland cannot be managed as if timber were simply another agricultural crop. State laws regulating private forest practices are becoming more common. The Endangered Species Act has the potential to lead to large-scale restrictions on timber management in old-growth forests of the Pacific

Figure 6-8-Forest Fires in the United States, 1924-87



SOURCE: U.S. Department of Agriculture, Forest Service, *Report* of the *Forest Service, Fiscal* Year 1990 (Washington, DC: USDA, Forest Service, 1991).

Protection of the northern spotted owl under the Endangered Species Act *is limiting timber management in the Pacific Northwest.*

Northwest (spotted owl habitat) and perhaps in the pine forests of the South (red-cockaded woodpecker habitat).

The Forest Service has responded to the growing concerns over the impact of timber management by establishing ‘‘Ecosystem Management” as its new approach (69, 71). Although not yet fully developed or defined, this approach promises to lead to significant changes in management. Ecosystem management addresses the services and the quality of the overall forest environment, rather than the production of a single species or commodity. To some, it means managing the forest so that it more closely mimics the structure of a natural forest (21). Harvesting might be designed to mimic the role that natural mortality from fire or insects played in removing trees from the natural forest. It is unclear whether Ecosystem Management will necessarily lead to a reduction in timber harvesting from National Forest lands. Other administrative and legal actions, however, almost certainly will. For example, the Forest Service has recently proposed ending “below-cost” timber sales-a change that would eventually end commercial logging on more than one-third of the National Forests (72).[9] The plan for protecting spotted owl habitat in the Pacific Northwest will also reduce timber sales well below the levels harvested there in the 1980s (31).[10]

Against the background of increasing constraints on timber management is the rising demand for wood products. The Forest Service projects that consumption of wood will increase 50 percent by the year 2040 (89). The increased supply of timber is anticipated to come from higher productivity and intensified management on private forestland. The forestland of the South is expected to increase in importance as the major source of timber. The area in intensively managed plantations in the South-now about 20 million acres-is expected to double over the next few decades (90). The restrictions on harvests in the Pacific Northwest may also lead to intensified harvesting pressures elsewhere in the country.

FORESTS AND CLIMATE CHANGE

Forest management has always been a challenging endeavor due to the long-lived nature of forests, the varied random events that perturb them, and an incomplete understanding of frost development and structure. A climate change, especially rapid climate change, would impose an additional severe challenge to this already difficult management situation. It is not yet possible to project with any precision the future climate for specific forest regions. Neither is it well established how forest development might proceed under a changed climate, particularly with elevated concentrations of atmospheric carbon diox-

[9] Below-cost timber sales are those for which the Forest Service receives less revenue than it incurs in expenses preparing for and administering the sale.

[10] The virtual freeze on lumbering that had been in effect in recent years will be relaxed, however.

from forest fires, insects, and pathogens might be driven by climate change is also unknown. Despite these uncertainties, it is known that climate and shorter-term weather extremes are important regulators of natural-forest structure and health. Climate is the long-term regulator of forest distribution; weather extremes and iweather-related stresses are the primary drivers of changes in forest structure.

The projected global temperature increases of 5 “F (3 ‘C) could mean that the ideal range for many forest species shifts north by 200 to 300 miles (33, 34, 50). In the long-term, perhaps after many hundreds of years, species will gradually migrate or compete to become established in new ranges, changing the composition of forests. However, the slow rate at which trees mature and the limited distance over which seed is naturally dispersed by wind and animals (15, 68) are thought to limit forest migration to about 25 miles per century. In the mean time, forests stranded in a climate unlike that of their present range maybe exposed to stresses that will lead to declining growth rates and increased mortality. The vulnerability of a forest to climate change may depend upon the forest’s location, biology, and management. Whether the effects of climate change are of concern, will depend upon the purposes for which the forest is owned or managed. Changes in forest condition may trigger adjustments in regional timber industries and alter the recreational and amenity services provided by each region’s forests.

The Long Term

Climatic variables, principally temperature and moisture, establish the geographic range of plants, animals, and ecosystems. The current distribution of forests represents species assemblages adapted to the range of today’s climate. Climate change can alter this mix. The ultimate response would be a change in the geographical distribution of species and in forest community types. There could be impacts on reproductive biology, on the efficiency of resource acquisition and use, and on the relative competitiveness of the species in each community. If climate change is rapid, new trees that become established may themselves later be threatened by the continuously changing climate.

The very long-term effects of climate change may vary widely by region, but they are expected to include a shifted and reduced range for many tree species, along with changes in the species composition of forests. In the end, some forestland could become more productive as longer growing seasons, greater warmth, and rising atmospheric CO_2 concentrations promote growth. Other forest regions could decline due to the drying effects of warmer temperatures, changes in the seasonal distribution of rainfall, or the inability of existing trees to compete against grasses, shrubs, and less-valued trees.

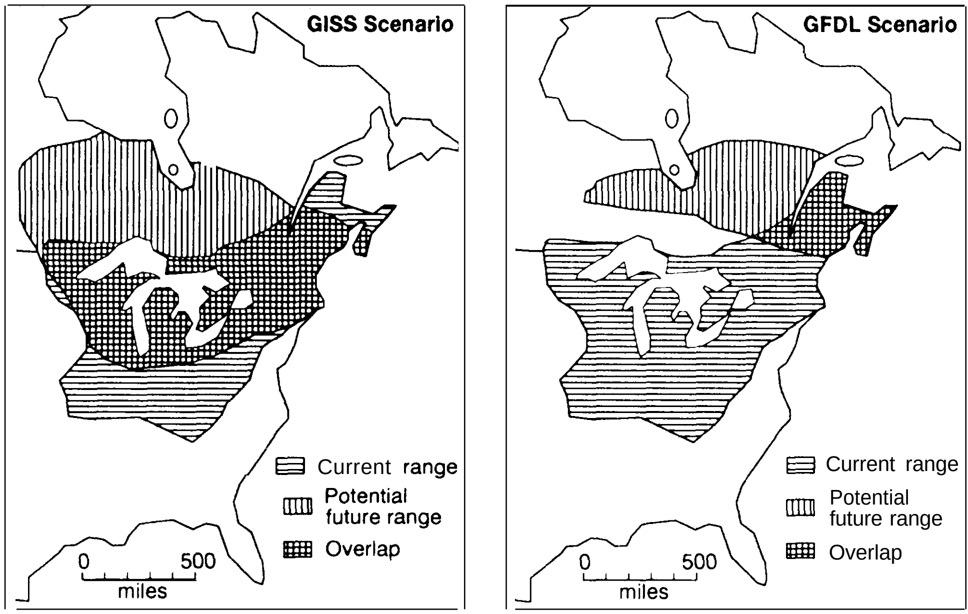
Various methods have been used to predict long-term forest responses to altered climate. Some researchers have attempted to relate climatic requirements of individual tree species to the conditions thought to be likely under a future climate.[11] 0thers have looked at historical changes in vegetation-those that occurred during the warming that followed the ice ages—to predict future vegetation changes.[12] Mathematical simulations of forest growth provide an alternative approach to estimating the response of forests to a changing climate (5, 74).[13] The general conclusions from these predictive exercises suggest that productivity in areas where cold temperatures

11 This technique has been used to e xamine potential effects of future climates on forests in California (1 16), the Southeast (53, 116), and the western United States (46).

12 Past distributions of vegetation can be reconstructed by using fossil pollen from the periods of abrupt climate change during the last glacial transition (59). These distributions have been used to model the Iong-term response of current forest vegetation to a change in climate (58, 61).

13 Simulation techniques have been used t. model forest development in the eastern United States (62, 79, 110), the Alaskan boreal forest (4), and the Pacific Northwest forests (14, 40).

Figure 6-9—Current and Projected Range of Sugar Maple under Two Models of Global Warming



NOTE: GISS=Goddard Institute for Space Studies; GFDL=Geophysical Fluid Dynamics Laboratory.

SOURCE: Office of Technology Assessment, 1993, adapted from M.B. Davis and C. Zabinski, "Changes in Geographical Range Resulting from Greenhouse Warming: Effects on Biodiversity in Forests," In: *Global Warming and Biological Diversity,* R.L. Peters and T.E. Lovejoy (eds.) (New Haven, CT: Yale University Press, 1992).

now limit growth will eventually be enhanced, productivity in areas where moisture limits growth will be reduced, and the ranges of all species will be shifted northward or up-slope. Any more specific predictions about long-term effects of climate change, several of which are described below, are often highly dependent on particular assumptions about soils, forest development, and climate changes.

New England's coniferous forests and sugar maples might be replaced by oak-hickory forest types (60, 79). Beech and sugar maple may die out across most of the northeastern United States (16). The present geographical range of sugar maples and the potentially suitable range under doubled CO_2 is illustrated in figure 6-9. The boreal forests of Alaska (spruce, birch, and aspen) might be converted to aspen or to steppe-like vegetation (4), and the boreal forests of Minnesota might be converted to northern hardwoods (6). Where there is adequate moisture, net productivity in these northern forests could be increased with the increased warmth and longer growing season. Other forests of the continental interior that are already subject to moisture stress maybe lost-reverting slowly to grass or stunted woodland (8, 62).

The potential range of the southern pines could move north into the present hardwood forestland of Pennsylvania and New Jersey (52, 53,79, 110). Valuable forestland of the Southeast from South Carolina to the Gulf Coast may become marginal for timber production due to temperature extremes.[14] If there is a shift in the range of the

[14] Those predictions are based 011- pine forests and do not take into account the ability of tree breeders to select and introduce more-tolerant varieties on plantation forests.

loblolly pine forests into more mountainous northern regions, it could mean higher costs of timber management. Rising sea levels in the coastal plain could threaten perhaps 10 percent of the southern pines and some of the associated pulp and paper mills (29).

In the West, the range of ponderosa pine is predicted to move up-slope at the expense of species that are less tolerant of dry soils, such as firs (46). The Douglas-fro may expand or at least maintain its range over most of its commercially important distribution. The upper elevation of Douglas-fir is expected to move up-slope (14); coastal Douglas-fir stands are expected to be relatively unchanged. Douglas-fir stands in drier regions may be lost, however.

The potential effects of elevated CO_2 on long-term forest productivity are not well-understood. Trees, like other plants, are expected to benefit from elevated CO_2 by showing improved growth and greater efficiency in water use. Laboratory studies do, in fact, find that seedlings of many tree species respond positively to elevated $C0_2$ (36, 43, 53). However, the large size and long life span of trees make extended experimental studies difficult. There are some indications that the increases in productivity do not continue over long time periods or if nutrients and/or water are limiting (3, 64). Forest trees face competition from other trees and plants. Those species most favored by elevated CO_2 may not be the species that are valued within the forest; for example, more rapid growth by shrubby or small trees could tend to suppress development of larger species. For these reasons, many researchers are cautious in extrapolating from experimental studies that show increased growth rates to ecosystem effects.

The Transition Period

The frost observable effects of climate change will not be so much climate-related as weather-related.[15] The near-term effects of climate change will be driven by changes in weather extremes and mediated through those stressors that have always been the primary controllers of forest structure and health-insects, disease, winds, and fire. Even in regions where forest productivity may be ultimately improved, the transition period could be extended and punctuated by sudden dieback and decline.[16] Forests are complex, long-lived systems that can only slowly adjust to climate but that can suddenly be threatened by weather-related stresses.

The near-term response of forest systems to climate change will involve complex reactions to new averages, new patterns, and new extremes in weather variables. Some forest species that are specialized to current climate conditions may not thrive (44). Altered patterns of exposure to high and low temperatures could mean that winter chilling requirements will not be met (38). Flowering, seed-formation, and seed-dispersal processes could be disrupted especially if pollenators do not adjust to changing conditions (11). With longer growing seasons, trees might add more light earlywood relative to the dense latewood that forms at the end of the growing season (66). This would mean a lower-quality wood for structural lumber and higher costs for pulp mills. Changes in early-growing-season weather conditions, particularly moisture and frosts, may effect the establishment of seedlings. Warmer and moister weather might favor the spread and boost the significance of certain fungal diseases and insect pests. Elsewhere, the drying effects of higher temperatures could be especially damaging, especially where the frequency of drought is increased. Associated with droughts would be

15 Thoughtful discussions of the importance of clearly defining climate (average) vs. weather (extreme) effects are provided in references 22 and 23. See also chapter 2.

16 A model of the increase in atmospheric CO_2 that could result from the dieback in forests is discussed in reference 39. The potentially large release of CO_2 to the atmosphere could speed up the rate of climate change.

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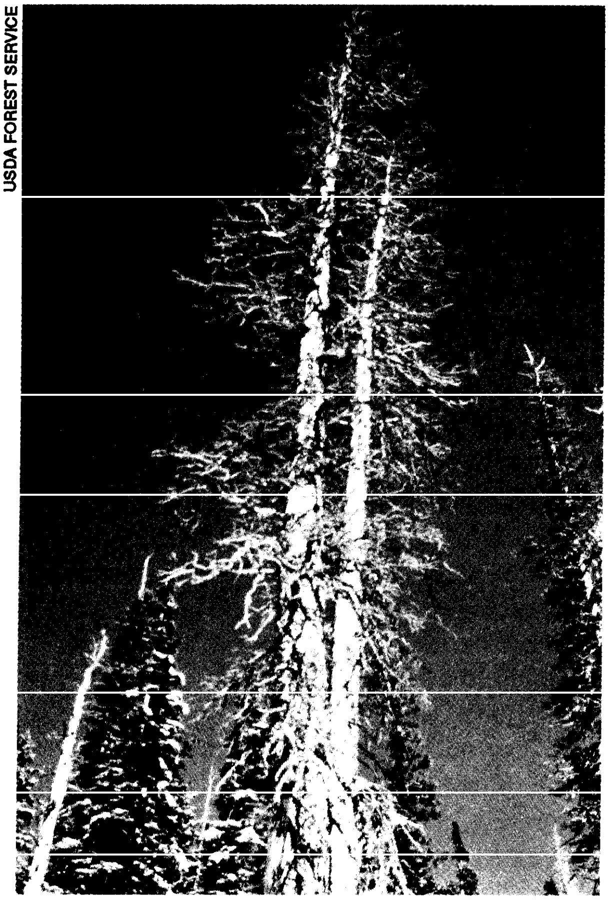


Drought-damaged trees in Colorado. Warmer climate may increase forest mortality from climate-related stresses such as drought, insects, and disease.

higher risks of secondary threats from forest fires and insects (51). Insect darnage may increase, for example, if insect pests produce more generations or persist longer during the tree-growing seasons (1, 27).

The initial effects of climate change will not at first be easily recognized as distinct from the effects of the normal regulators of forest growth and development. The potential initial effects of climate change can be illustrated by current weather-related stresses on selected highly valued tree species in several regions of the United States, described in box 6-F. The potential vulnerabilities of forests, by region, are illustrated in table 6-3.

Factors Influencing Vulnerability to Climate Change

The vulnerability of a forest to climate change will be a function of the forest's location, biology, and management practices (see table 6-4). It will, of course, also be determined by the regional differences in the extent and pace of climate change. These differences will be influenced, in part, by latitude, altitude, proximity to continental margins, and distance from large water bodies.

Box 6-F-Current Weather-Related Stresses on Selected Forests

The Northeast: sugar maple-Sugar maple, a dominant tree species in the northern hardwood forest, is one of the most valuable hardwood trees in the northeastern United States. Sugar maple develops best in moist, well-drained, nutrient-rich soils. Unusually warm or cool weather during the growing season or drought can have serious implications for sugar maple health. Numerous insects and pathogens are linked to weather conditions. Defoliators, such as the tent caterpillar, the saddled prominent, and the maple webworm, are frequently associated with warm, dry weather (47, 84). Drought periods favor the spread of *Armillaria* root decay, the most important mot disease in maples. A lack of winter snow cover can cause deep roots to freeze and lead to death of the tree (30). For sugar maple, changes in temperature ranges and in soil moisture have the potential to exacerbate insect stress, disease, and general decline.

The South: loblolly pine—Loblolly pine is the most commercially valuable tree species of the southern United States. The natural distribution is mostly contained within the Coastal Plain and Piedmont regions from

Virginia to eastern Texas. It is often mixed with shortleaf or longleaf pines, dominating these stands in areas with high soil moisture. Numerous important biotic stressors of loblolly pine are intimately related to weather conditions. The southern pine beetle is the most destructive forest insect of the Southeast. Prolonged drought stress and warm weather favor expansion of beetle populations, predisposing trees to being attacked and allowing extra generations to develop during the growing season (26, 27). Fungal diseases, such as fusiform rust, which causes significant economic loss, are favored by warmer and moister weather conditions (93). Fires can be a significant factor in shaping these forests. An increased fire frequency, which might result under warmer and drier conditions, would favor longleaf pine or shrub growth over loblolly pine. Increased frequencies of hurricanes or major storms would add to existing risks to pines of the coastal plain. Warmer weather, with or without altered precipitation, is judged to have the potential to increase the risks to most southeastern forests.

The Mountain West: ponderosa pine—Ponderosa pine is extensively distributed west of the Great Plains, primarily at lower elevations and relatively dry sites. Many of its insect and pathogen stressors are linked to weather cycles. The most damaging insects to ponderosa pine are bark beetles, which are favored by drought conditions. For example, during the drought in the late 1960s, California saw increased ponderosa pine mortality due to beetle activity (93). Fires in much of the ponderosa pine regions are frequent, often large, and sometimes damaging. Although ponderosa pine is favored in a fire regime, the overall productivity of the forest could decline with more frequent fires. Any increase in the frequency of lightning strikes or in drought severity will increase the risk of fire. Because of the dry habitat of ponderosa pine, this species may become more competitive undera warmer climate (46). Success at the stand level, however, depends more on near-term weather events and the interactions of weather extremes with pest, fire, and other stresses.

The Pacific Northwest: Douglas-fir—Douglas-fir is the most important commercial tree species of the Northwest. The Douglas-fir has developed in a region dominated by wet winters and dry summers. Much of the morbidity, mortality, and growth loss in the Pacific Northwest is caused by dwarf mistletoe infection and stemwood decay. These stressors are not particularly important in the more productive coastal forest and do not appear to be regulated by weather. insect defoliators are relatively unimportant in the moist coastal forests. Root diseases, which are of somewhat greater concern, seem to be only indirectly affected by temperature. With the relatively long interval between fire and wind events and with the lack of climate-driven stress, it appears that the coastal Douglas-fir forests will be relatively resistant to near-term stresses under a changing climate, unless there is severe drying. Insects and fire present a greater risk to the Douglas-fir in the less-humid interior West. Outbreaks of the Douglas-fir tussock moth occur in the drier regions where fir overlaps in range with ponderosa pine. The western spruce budworm and Douglas-fir bark beetle can also be damaging to fir growing under drier conditions. Extensive mortality from insects and disease has already occurred in the Douglas-fir of the drought-stricken Blue Mountains of eastern Oregon (see box 6-E). Further drying under climate change would be very damaging to the Douglas-fir of the interior West.

Alaska: spruce-White and black spruce are the principal components of the boreal forest of interior Alaska. The environment of interior Alaska is harsh, and abiotic stresses are numerous and severe. Fire is an integral part of the ecosystem. Snow, ice, and wind damage are frequent, and permafrost development and poor soil drainage are often problems. The most damaging forest insect in Alaska is the spruce beetle, a bark beetle that is very sensitive to weather events. Extended growing seasons would increase the period of exposure to beetle populations and allow for greater damage. The weather-related nature of the many stresses on these forests suggests that they could be rapidly affected by a changed climate.

SOURCE: Office of Technology Assessment, 1993; W.H. Smith, "United States Forest Response and Vulnerability to Climate Change," contractor paper prepared for the Office of Technology Assessment, June 1992; C.F. Cooper, "Sensitivities of Western Ecosystems to Climate Change," contractor paper prepared for the Office of Technology Assessment, August 1992.

Table 6-3–Forest Vulnerability

Region	Tree	Potential stressors/key climate factor and vulnerability
Northeast North Central	**Maple**	Insect **defoliators/warm, dry weather** *Armillaria* (root **decay)/drought** **Deep root freezing/lack of winter snow cover** **Vulnerability: High potential** for damage with warmer temperatures; drier conditions
Southeast	**Loblolly pine**	Southern pine beetle/prolonged hot, dry weather Fungus (fusiform rust)/warm, moist weather Fire (favors Iongleaf or shrub)/warm, dry weather Storm damage/increase in coastal storms Vulnerability: Potential for much warmer weather (with increase or decrease in precipitation) to reduce productivity.
Rocky Mountain/ Pacific Southwest	**Ponderosa pine**	Borers, bark beetles/drought Fire/drought or lightning **Vulnerability:** If stands can overcome fire and insect risks, maybe more competitive in warmer weather since adapted to warm, dry climate.
Pacific Northwest (Coastal)	**Douglas-fir**	Most stressors not strongly weather related. **Vulnerability: Resistant** to near-term climate change, though productivity may decrease.
Alaska	**Spruce**	Spruce beetle/warm weather (speeds insect development), moisture problems, erratic freezes **Vulnerability:** High potential for rapid effects because climate plays pervasive role.

SOURCE: W.H. Smith, "United States Forest Response and Vulnerability to Climate Change," contractor paper for the Office of Technology Assessment, June 1992

Location

***The* greatest climate** perturbations will probably be associated with the more northern U.S. latitudes, so forests there may be most at risk of disturbance. However, in areas where low temperatures now limit growth, the longer growing season and warmer climate may ultimately become more hospitable to forest productivity. Forests with small or highly fragmented ranges may be at particular risk of loss from climate change (e.g., forests at the upper elevation of a montane environment may simply have nowhere to go). Other forests in montane environments may beat low risk over the long term because they need migrate only a small distance to find a more suitable climate zone. Forests located in coastal regions may be at risk from rising sea levels-with the threat of flooding, saltwater intrusion, and poor drainage to increases in damaging winds. Forests in already dry continental interiors may be at risk of soil-moisture limitations because continental interiors are expected to dry more than are continental margins. Forests already under stress will beat high risk. The Fraser fir and red spruce of the Appalachian Mountains, already threatened by numerous stresses, including pollution, may be lost. Forests in locations subject to droughts, fire, and wind damage will be at increased risk if the frequency or intensity of these stressors is increased.

Forest *Biology*

***Species* that are able to use increased $C0_2$** efficiently will have an advantage over other species (see ch. 4). Likewise, species that distribute seeds widely may fare better under climate change. A mixed-species forests might tolerate a wider variety of changes than would a single-species forest. Individual trees with a low tolerance for climate fluctuations would be least adaptable to ongoing climate change. Individual populations with little genetic diversity among

Table 6-4-Characteristics of Higher-Risk Forests

Forest location	Forest biology	Forest management
Higher latitude Higher elevation Continental interior Maritime sites Forest-range boundaries Low-productivity sites High-fire-risk sites Drier sites	Small, fragmented range No or few migration corridors Low genetic variance Low species diversity Genetically specialized to site History of widespread dieback Heavy seed	Fragmented forests Less-diverse forests High stand density Inappropriate species

SOURCE Office of Technology Assessment, 1993

trees might prove to be at greatest risk of long-term decline.[17] The genetic composition of tree populations tends to vary over the species range. Species that are highly adapted to local climate and soil conditions may beat high risk to climate change across their full geographical range (45, 67).

The stage of forest development is also an important factor in forest vulnerability to climate change. Seedlings are especially sensitive to heat and soil-moisture extremes, and their risk of damage from climate change may be high. Older stands, past the period of vigorous growth, are prone to insect defoliators, bark beetles, and root disease (42). Younger, vigorous stands, presumably able to withstand stresses, maybe least at risk.

Management *Status*

The most intensively managed industry and private forestland may be least at risk of catastrophic loss or long-term decline because efforts to reduce such effects will be undertaken. Private forest managers have both the financia1 incentive and the latitude to protect against extensive loss from climate-related threats. They can use several available techniques: short rotations to reduce the length of time a tree is exposed to an unsuitable climate; planting better-adapted varieties or varieties developed through selection and breeding programs to reduce vulnerability; and thinning, weeding, managing pests, removing fallen wood, irrigating, improving drainage, and fertilizing to improve general health. These actions reduce the likelihood of moisture stress and of secondary risks from fire, insects, and disease. Thinning, for example, reduces competition for moisture and can effectively increase tolerance to drought;[18] it may also speed development of a climate-adapted forest by removing trees that are growing poorly.

Planting single-species forests might seem to pose increased threats of 1oss from insect pests or disease due to Limited genetic diversity (63). Yet surprisingly, commercial tree species show a tremendous genetic diversity among individuals-even among trees from the same parents (41). This inherent diversity could make trees less likely to succumb to a single pest or disease than are most agricultural crops (37). Forests managers attempt to ensure diversity in the seedlings they use to establish their forest stands even if they are planting single-species forests.[19] Nonetheless, a healthy mixed-species, mixed-age forest is probably less susceptible to insect infesta-

17 In general, trees show a high degree of genetic diversity among individuals-eonsiderably more than do animals Or most other plants (41).

18 The contrast between thinned and healthy industry forestland and adjacent, drought-stricken public forestland in Idaho is Striking (D.F. Smith, Vice President, Timber[and Resources, Boise-Cascade Corporation personal communication and videotape, June 1992).

19 W. Jarck, Director of Forest Resources, Georgia-Pacific Corporation% personal communication, May 1993.

tion than are extensive contiguous areas of uniformly aged forests.[20]

Less-managed forests may not be inherently at any greater risk than actively managed forests. However, once a decline in forest health begins, less-managed forests may face greater tire and pest damage. At particular risk will be those forests already subject to moisture stress and fire hazard. Once they are subjected to stress, wilderness forests and National Parks may be at elevated risk of substantial decline due to policy restrictions imposed on silvicultural and pest-management activities. Similarly, because management is currently limited on most National Forest lands and the less-productive nonindustrial private forestland, those forests could be at risk of unchecked loss. If the general health of these forests declines, vulnerability to large-scale mortality could increase.

Forest Values at Risk

The services for which forests are managed range from the protection of naturalness (see ch. 5) to timber production. The significance of forest decline or change depends almost entirely on what the forest is being used for. For example, decay of the trunk and loss of timber would be of great concern in a forest managed for wood products. However, it would be relatively without consequence in a forest managed for watershed protection, and could be of value in a forest managed to favor habitat for cavity-nesting birds.

Commercial Timber Products

Forests maintained for the production of wood products and fiber would benefit from any near-term or long-term increase in productivity. Reduced growth or increased mortality would have a damaging effect on them. Managers of industry forests and other private timberlands can be expected to respond with adaptive measures if and when they perceive changes in climate and market conditions. Although no timber company is altering forest practices today, some are actively preparing for the types of risks posed by climate change. Weyerhaeuser, for example, is conducting experimental silvicultural programs to examine the effects of thinning practices on ameliorating the effects of droughts (19). It is also sponsoring research on the genetics, physiology, and biotechnology of heat- and drought-tolerant seedlings. Such technological developments should help protect the timber industry and future wood supplies.

Despite the possibility of some adaptive management responses, climate change could still be very costly to the timber industry. In the southern United States, declining timber volumes could lead to $300” million in lost annual revenues, whereas the increased management measures needed to compensate for poorer conditions could add $100 million to the annual costs of production (29, 66). A sea level rise could force the movement of coastal pulp and paper mills, further increasing the costs of climate change. Some of these mills would cost as much as $1 billion to replace.

For the Pacific Northwest, an expanded up-slope range of the Douglas-fir forests might add some 5 percent to the regional timber harvest (29). However, the increased costs of logging at higher elevations could offset much of this potential gain. Furthermore, with the increasing institutional and environmental constraints on harvesting in the Pacific Northwest (e.g., the spotted owl recovery plan), increased harvest levels from this region seem unlikely.

Recreation, Wildlife, and Amenities

Modest changes in forest productivity may have little impact on the recreational or aesthetic values of the forest. However, extensive dieback and mortality could have considerable impacts. A study of the economic costs associated with forest mortality caused by an insect infestation in the Front Range of the Colorado Rocky Mountains

[20] R. Hedden, Professor, Department of Forest Resources, Clemson University, personal communication, January 1993.

gives a sense of the importance of these recreational and aesthetic values (113). Each household in the region would have been willing to pay almost $60 per year to avoid the reduced attractiveness of the forest caused by insect infestation. Dry timber in dead forests adds to fire risks, threatening adjacent forests and property (see box 6-G). Indeed, the costs of removal of dead trees and the temporary loss in property value in the urban and suburban settings might be among the highest costs associated with climate change.

Longer-term change in forest composition may be of little significance to the value of some services, including providing recreation, enhancing landscape and water quality, and protecting against soil erosion. However, certain species that depend on the unique structure of an existing forest could be at great risk (e.g., Kirtland's warbler and the spotted owl). The costs of protecting threatened and endangered species could rise considerably if it becomes difficult to maintain specialized habitat (see ch. 5). The production of certain forest outputs-for example, seeds, nuts, pharmaceuticals, resins, and syrup—is also highly species dependent. Similarly, some tourist and recreational activities

Box 6-G-Private Property and Fire Risk

If climate change leads to drier conditions in forested areas (as some climate models predict), wildfire risk is likely to increase as trees become more susceptible to disease and mortalit y. Because of recent droughts and 100 years of fire-suppression policy, many forests are already experiencing massive diebacks and holding excessive fuel loads. Over half of some western forests, like those in the Blue Mountains in Oregon (see box S-A), contain dead and dying trees and are especially prone to catastrophic fire (92). Combining prescribed fire and a gradual reintroduction of the natural fire regime to some forested areas is one proposed way to reduce fire risk in places already primed for wildfire as well as to reduce risk in a drier climate (48). However, many forests are already so dry that even controlled burning carries unacceptable risks of turning into an uncontrolled wildfire. In addition, a natural fire regime in many natural areas is much less feasible now than 150 years ago, when preserves contained virtually no development. Because natural areas are increasingly popular places for people seeking escape and solitude from urban life to build vacation and weekend homes, a "let-burn" policy is nearly impossible without destroying life and property.

Wildfires have contributed to significant losses in recent years. In 1990, eight large wildfires contributed to over $305 million losses in property damage—37 percent of total losses due to large fires in the United States that year. Over 700 homes were destroyed and 270,000 acres (110,000 hectares)[1] burned. Wildfires were the largest single type of fire in 1990, and in all fires with large losses, dry weather and vegetation were named as major contributing factors. More recently, fires near Lake Tahoe, caused by extremely dry weather conditions, charred 24,000 acres, destroyed over 30 homes, and incurred roughly $250 million in damage.

As climate becomes drier and more people build vacation *and* weekend homes on forestland, the potential losses due to uncontrolled wildfire become even more devastating. As widespread use of prescribed fire in these areas to reduce fuel loading becomes less feasible-because it carries great risks of becoming uncontrollable—alternatives to reduce fire risk must be examined. The sheer magnitude of the problem makes it impossible to enforce codes on all properties. Also, the public benefit derived from using risk-reducing measures on private property is not recognized as a public benefit. Conversely, private owners are not held liable for neglecting to use fire safety measures that result In passing the fire risk to adjacent lands. In addition, It Is generally accepted that the public agencies ultimately have the responsibility to protect homes from fire.

[1] To convert acres to hectares, multiply by 0.405.

(Continued on next page)

Box 6-G–Private Property and Fire Risk-(Continued)

Although many aspects of this problem are best handled by State and local authorities, there are opportunities for Federal involvement, especially for areas containing large Federal holdings mixed with private parcels. Some possible land-protection measures include fuel management (thinning dead, flammable wood) combined with a conversion to a less hazardous type of tree around structures and in strategic locations such as ridge tops. This “fuel-break” method has proven effective in saving life, property, and fire-suppression costs. It is costly, however, and may therefore be feasible only in smaller areas or in areas where the fuel breaks are used for multiple purposes (e.g., wildlife, recreation, and rangeland) to offset the costs. Opportunities for the Federal Government to encourage fuel-break use on lands mingled with public land include outright purchase of land or an easement agreement where the private landowner is paid to let the public agency build a fuel-break system using some of the private land. Improvements in fuel-defense systems through road building and enhanced water facilities may be feasible in some areas, but less so in or near areas where such development is restricted (i.e., wilderness areas). An improved fire-alert system that informs residents about critical fire and weather conditions regularly could also reduce risk. Although this may be most appropriate for State and local authorities, the Federal agencies could play a vital role for residences in or near public holdings.

Although some management actions may partially reduce fire hazards, fire risks are likely to remain for dwellings in natural areas in the future. The presence of private homes in preserves poses an enormous problem for land managers in dangerously dry areas. There are no dear solutions. A growing population will continue to be drawn to remote areas, and a drier climate will increase fire risk in National Forests. Although a natural fire regime or a let burn policy maybe the best ecological solution, it may no longer be feasible in wild land tamed by the presence of private homes.

SOURCES: K.T. Taylor and MJ. Sullivan (ad.) (Quincy, MA: NFPA, May 1992); Anonymous, "Sierra Fire Battle Heats Up," *Reno Gazette-Journal,* June 28,1992, p.1A; Forest Service, *Blue Mountains Forest Health Report: NewPerspectives in Forest Health* (Portland, OR: USDA, Forest Service, Pacific Northwest Region, April 1991); USDA, Forest Service, *Protecting Residences from Wildfires: A GuMs for Homeowners, Lawmakers, and Planners,* prepared by H.E. More, May 1981.

depend on the nature of the existing forest (e.g., enjoying the colors of autumn foliage and the old-growth and giant sequoia and redwood stands). For example, a northward retreat of the sugar maple could have significant effects on the tourist industry of the Northeast.

RESPONDING TO CLIMATE CHANGE

The Federa.lGovemment plays several primary roles in forestry, all of which may be relevant in responding to climate change concerns. The Government must plan for and manage its own forests, which make up about one-quarter of the total U.S. forestland and include much of the less-managed forestland. The Government also has a cooperative role in protecting and monitoring the health of nonindustrial private forests. Federal forest research, monitoring, and assessment efforts will also be valuable in facilitating better adaptation to climate change within the private forest sector. The array of major Federal laws and programs under which forest management and research is regulated or influenced is presented in table 6-5.

The Federal Government could respond to the threats that climate change poses to forests in various ways. Forest-management practices—such as seeding, tree planting, thinning, harvesting, and free, weed, and pest control—might be designed to delay or offset forest decline or to take advantage of new opportunities. Institutional responses—incentives programs, cooperative

Table 6-5--Major Federal Acts or Programs Affecting the Use of Forest Lands[a]

Act or program	Implementing agency	Effect of program
Federal land management		
Federal Land Policy and Management Act (1976) (P.L, 94-579)	BLM	Provides BLM authority for land management.
Forest and Rangeland Renewable Resources Planning Act (1974) (P.L. 93-378)	USFS	Authorizes overall USFS planning and the assessment of forest-resource trends
Multiple-Use Sustained-Yield Act (1960) (P.L. 86-517)	USFS	Sets principles of USFS land management.
National Forest Management Act (1976) (P.L. 94-588)	USFS	Prescribes individual forest-planning requirements
National Park Service Organic Act of 1916 (P.L. 85-434)	NPS	Provides general principles for management for NPS management.
Wilderness Act (1964) (P.L. 88-577)	USFS, NPS, BLM	Provides general principles of management for wilderness reserve systems.
Federal research		
Forest and Rangeland Renewable Resources Research Act (1978) (P.L. 95-307)	USFS	Authorizes USFS research role in forest management and forest products.
Federal cooperative role		
Cooperative Forestry Assistance Act of 1978 (P L. 95-313)	USFS	Authorizes cooperative programs in forest health and promotes private forest productivity.
Farm Bill (1990): Forestry Title (P.L. 101-624, Title 12)	USFS	Authorizes programs to promote multiple-use management and protection of private forests.
National Forest Dependent Rural Communities Economic Diversification Act of 1990 (P.L. 101-624, Title 23)	USFS	Promotes diversification of economies that are timber-dependent.
Renewable Resources Extension Act (1978) (P.L. 95-307)	USFS	Authorizes extension service programs in forestry.
Other legislation		
Clean Air Act of 1970 (as amended) (P.L, 91-604)	EPA	Limits prescribed burning.
Clean Water Act of 1972 (as amended) (P.L, 92-500)	EPA	Limits forest management near waterways and wetlands.
Endangered Species Act of 1973 (P.L. 100-707)	DOI	Restricts forest management if necessary to protect endangered species.

[a]DOI=U.S. Department of the Interior; BLM=Bureau of Land Management; NPS=National Park Service; USFS=U.S. Department of Agriculture, Forest Service; EPA=U.S. Environmental Protection Agency

SOURCE: Office of Technology Assessment, 1993.

Table 6-6–Suitability of Silvicultural Practices

Silvicultural practices	National Forests	National Parks	Industrial	Small land owners
Shorter rotations	Low	Low	High	Intermediate
Thinning	Intermediate	Low	High	High
Site preparation	Low	Low	High	Intermediate
Planting	Intermediate	Low	High	Intermediate
Manage to promote mixed species	High	Low	Low	Intermediate
Prescribed fire	Intermediate	Low	Low	Low

SOURCE: W.H. Smith, "United States Forest Response and Vulnerability to Climate Change," contractor paper for the Office of Technology Assessment, June 1992

support, research, monitoring, planning, and policy setting-can serve to reduce the social impacts of change.

Perhaps most importantly, the Federal Government could ensure technical preparedness for quick response in the event of large-scale mortality. Central to such planning would be the development of the storage capacity and the field testing of a variety of seeds.

Federal Forestland

The large Federal share in forest ownership allows a significant, direct Federal role in preparing for climate change. Nevertheless, deciding how or when to respond will not be straightforward. Although forest-management activities could speed forest adaptation, any intensification in management activity might be controversial if broadly applied to public forests. On Federal forestland, the response to climate change must depend very much on the different services of the forests and on the degree to which those services are threatened.

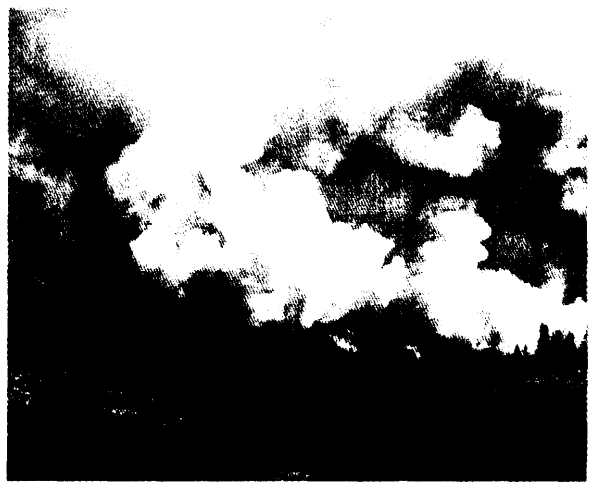
The management approach used on Federal forestland ranges from preserving natural systems to the moderately active timber management found on some multiple-use forests (see box 6-C). Forestland within the wilderness reserve system is by law off limits to active timber management. Within the National Parks, manipulation of the forest resource is held to the minimum needed to preserve the ecological integrity of the park. The more extensive multiple-use forestland, including the National Forests managed by the Forest Service and the smaller area of forested lands managed by BLM, is generally available for timber management. Even on this land, the intensity of management is rarely high. Much of the multiple-use forest is valued primarily for its recreational or aesthetic services; other areas are remote and not very productive, making them too costly to manage.

For Federal forestland, climate change may present some difficult challenges. Under rapid and substantial climate change, it is unlikely that all services of the public forests could be maintained. The threat of large-scale mortality or the extinction of forest species might call for unusual and costly management interventions to facilitate forest protection or forest migration-perhaps even on those lands where active management is now prohibited. The intervention that might be required to sustain or restore the long-term services of the Federal forest resource may be inconsistent with protecting the naturalness or the recreational services for which many public forests are valued. In table 6-6 the suitability of various silvicultural practices to different forest lands is summarized.

For the National Park Service, the realities of global climate change may raise questions about the mandates for forest management and protection provided for under existing management policies and laws. How much effort should be spent to preserve and protect a forest system that is out of phase with the current climate? Will the policy restrictions on active forest management and pest control endanger some of the very resources that the Parks were created to preserve? (See ch. 5.) For the National Forests and BLM forestland, climate change may raise challenges to the sustained yield concepts and multiple-use practices (see box 6-C). Can the promises of stability implied by the sustained-yield philosophy be maintained against the backdrop of a declining forest? With the restrictions on timber management practices, will managers have the flexibility needed to respond to the perhaps greater threat that climate change may pose to the recreational and amenity services of the forest? With the contentiousness of the current National Forest planning process, will there be the institutional strength or sense of direction needed to act with the foresight that may be required during a period of rapid climate change? The Forest Service and BLM manage extensive areas of grasslands, in addition to forestlands. Some issues related to grasslands are discussed in box 6-H.

Given the potential for significant forest decline, the long time needed to regrow a forest, and the slow rate at which any management responses can be implemented across the large areas of forestland, developing the institutional preparedness to guide future action may be a useful first step. It would also be helpful to conduct a policy review to determine acceptable rules for interventions that would protect forest health or to restore Federal forestland after widespread mortality. Strategic planning could include contingencies for responding to sharp forest declines under future climate change.

It is also important to develop the technical preparedness that would allow a rapid and effective future response to large-scale forest decline--in case the need arises. In research, attention should be paid to finding relatively low-cost and minimally obtrusive means for protecting forest health and for assisting with the restoration of forests after widespread decline. The effects of adaptive management practices and restoration


USDA FOREST SERVICE

A forest fire burns out of control. Uncontrollable and damaging forest fires are associated with long-term droughts. Warmer and drier climates may increase the frequency and intensity of these damaging forest fires.

techniques could be investigated in experimental forests. Other appropriate measures might include monitoring forest change and undertaking research about the sensitivity of forest species and ecosystems to a changing climate. Without that knowledge, it will be difficult to target future responses or research efforts effectively.

An expanded and better-coordinated program of storage for forest seeds and genetic resources could provide insurance against the possibility of substantial forest and species loss. The current systems for preserving seeds and genetic material of forest species are narrowly focused on a few commercial species and are inadequate for rebuilding the forest in the event of a worst-case decline. Associated with an expanded seed bank, research on effective approaches to large-scale forest restoration from seed or clonal material may be needed.

At a minimum, the Federal Government might want to ensure the capability of restoring forest resources in the event they decline sharply. Such a strategy might require only an expansion of existing programs on forest genetics and an associated research effort to develop restoration techniques. Understanding the possible means

Box 6-H—Public Grazing Lands: Management Dilemmas

The Bureau of Land Management (BLM) is the Nation's single largest manager of public lands, with jurisdiction over one-eighth of all land in the United States, which is more than the U.S. Forest Service, the National Park Service, and U.S. Fish and Midlife Service combined. These lands are generally used as rangelands (grazing lands) or managed for timber, depending on location and resources. The land-use policies that govern rangeland management have begun to come under dose scrutiny, with mounting pressure to raise grazing fees and to increase control over the use of these lands. BLM claims that US. rangelands are in better condition now than ever before, but conservation groups point to a lack of proper management and t he deterioration of many of t hese lands. Climate change effects resulting from temperature and seasonal changes will only exacerbate existing stresses. As t his Administration revisits current BLM polices regarding rangeland management, changes maybe made that address these and other concerns.

In 1976, passage of the Federal Land Policy and Management Act (FLPMA) (P.L. 94-579) gave BLM a multiple-use mandate for rangelands. In 1978, the Public Rangelands Improvement Act (P.L. 95-514) was passed with the goal of improving upon declining rangeland conditions. These congressional mandates were meant to guide BLM in developing and promoting sound mangement practices that would help to promote the wise use of resources on Federal lands. Part of this effort included inventory and monitoring protocols t hat would provide BLM with a picture of present range conditions and help document trends in range condition. In addition, the act instructed the BLM to develop and periodically review allotment management plans. Unfortunately, the agency has been unable to meet the mandates of these acts, and as a result rangelands have experienced extensive deterioration.

Many of the western rangelands have been exposed to severe overgrazing and mismanagement. Wetlands, riparian areas, and springs have been developed for livestock watering to the point of extreme environmental impact. As a result, many of these areas have experienced near complete vegetative loss and radical dedines in biodiversity. The environmental impacts of both are often staggering. Defoliation and exposure of the soil results in erosion and a loss of nutrients, as well as an increase in sedimentation and pollutant loading in nearby waterways. Such upsets in aquatic ecosystems have far-reaching ramifications for fish and other organisms dependent on aquatic health. A loss of biodiversity and the resultant influx of exotic species may, in some cases, be irreversible (65). Climate change and its effects may make recovery of some of these areas more difficult by futher stressing plant communities and water systems.

and consequences of restoration would require active experimentation on public forestland. Particular attention should be paid to finding low-cost and environmentally benign ways to facilitate migration and restoration of natural forests.

A more proactive response might call for increased efforts to improve the general health of the existing forest and to reduce the likelihood of forest free, pests, and drought damage. Such efforts might increase the forest's ability to face future climate threats. The uncertainties of climate change seem to suggest that there are few prescriptions that can be offered for immediate changes in management practices. However, it may be wise to begin to implement a diverse portfolio of strategies, experimenting with different strategies across a forest to provide some hedge against the risky future. This is often the best way to deal with risk.

Nonfederal Forestland

The Federal role in protecting the health of private forestland may take on greater importance under a changing climate. Nonfederal forestland comprises almost three-quarters of the Nation's total forestland. Along with its role in providing much of the Nation's supply of wood products, this forestland provides wildlife habitat, recrea-

Poor rangeland conditions are generally attributed to poor livestock distribution (65). In the past, BLM has addressed these “distribution problems” with water developments, grazing systems and other range “improvements,” which generally move livestock into areas previously lightly or unused, without making improvements in degraded areas (65). Range improvement projects are a major BLM management emphasis, however rangelands that are steep sloped or lacking in a water source are often relegated to livestock use and grazing. These improvements include spring development (by diverting water from natural springs to troughs), the construction of reservoirs (usually in wetlands or other natural depressions along watercourses), and large-scale vegetation changes on uplands (usually due to overstocking), all of which have contributed to a decrease in usable rangeland through resultant environmental effects. In some cases these areas can recover if livestock use is limited for prescribed periods of time.

Currently, two of the most debated issues surrounding public rangeland management are grazing fees and the land-use permitting process (57, 112). BLM collects a (per head) monthly fee for grazing cattle on Federal lands—a fee that is considerably less than would be charged on private lands. In addition, Federal permits are issued to ranchers, miners, and others who use the resources (i.e., water) on these Federal lands. The low fees are generally viewed, by all parties, as a necessary subsidy for the western livestock industry. In the past, industry proponents have balked at suggestions of raising grazing fees to bring them in line with market values. The current movement is to phase in the increase over a 3-year period, but after that time the new fees will still remain below those charged on most private lands. In addition, if rangeland management policies are revamped, the reissuance of grazing permits would be contingent on past management practices and could potentially be vvithheidforabuse of resources.

Decisions regarding the management of Federal rangelands are currently made by those with an interest in profitable resource consumption (i.e., cattle grazers). However, there has been increasing interest in how these lands are being used by the scientific and conservation communities, which are generally interested in preserving these resources for their ecological, recreational, and aesthetic value. As a result, BLM may begin to seek input on rangeland management issues from an expanded group of advisors.

SOURCES: New York *Times*, “Clinton Planning to Increase Fees on Grazing Lands,” Aug. 10, 1993; Public Employees for Environmental Responsibility (PEER), “Public Trust Betrayed: Employee Critique of Bureau of Land Management Rangeland Management,” a report written by BLM employees, Washington, DC, June 1993; *W/ Street Journal*. “U.S. Renews Its Efforta to Overhaul Grazing Policy, calling for Higher Fees,” Aug. 10, 1993.

tional opportunities, watershed protection, and amenities that are valued by the general public. To protect these services, the Federal Government plays a cooperative role in monitoring the health of these forests and in limiting forest fire and pest hazards. With climate change increasing the potential threat to forest health-adding to the threats of spreading forest fires and pests-the importance of existing programs of forest health monitoring and of cooperative support for forest protection will be enhanced.

The Federal Government has no direct regulatory role in nonfederal forestland. However, through a variety of existing programs, particularly under the Cooperative Forestry Assistance Act of 1978 (P.L. 95-313), as amended by the Forestry Title of the 1990 Farm Bill (the Food, Agriculture, Conservation, and Trade Act, P.L. 101-624, Title XII), direct financial *incentives can be* provided to owners of small forest areas for reforestation, forest improvement, and forest protection. The recently funded Forest Stewardship and Forest Legacy Programs have been innovative in their attention to maintaining the environmental services on private forestland (in contrast to the more traditional emphasis of the Forestry Incentives program on enhancing timber supplies). Cooperative support is also provided under the new programs to States and localities for forest health monitoring and for fire and pest control.

Existing Federal programs that help to diversify the economy of rural communities may also be increasingly important. Within the private sector, adaptive responses to climate change will occur as the owners of timberland, the related forest industries, and the consumers of forest products and services take action to reduce the threat to their income, property, or welfare. In the end, though, the timber industry will decline in regions where relative production costs have risen, perhaps abandoning some dependent communities. If this transition is sudden, the resulting local economic decline could become a source of public concern. A key to reducing the potential for such regional declines is to act now to improve the resiliency and adaptability of the forest sector.

The Federal Government can improve the adaptability of the forest sector through its support for innovation, particularly those innovations that reduce the dependence of local industry on forest species or log sizes that may not be available in the future. Forest Service research programs developed under the Forest and Rangeland Renewable Resources Research Act of 1978 (P.L. 95-307) have long supported such innovation in forest-product technologies and forest management.[21] Existing programs designed to improve the diversification of income sources within rural communities, such as were authorized under the National Forest-Dependent Rural Communities Economic Diversification Act of 1990 (P.L. 101-624; Title 23 of the 1990 Farm Bill), may become increasingly important, Small cost-sharing programs, such as the Economic Diversification Grant program and the Rural Development Initiative, have recently been funded to improve the stability of rural communities through diversification away from resource-dependent industry and through projects designed to promote flexibility and efficiency within the wood-products industry.

The process of adaptation within the private sector may also be improved if the Federal Government conveys accurate information about the risks and opportunities associated with climate change. Forest users should be aware of the changing nature of forests and the fact that change might be accelerated under a warming climate. The industry purchasing timber from Federal lands can best plan for the future if uncertainties in the future supply of timber are known and not misguided by false promises of sustained flows of timber harvests. A well-informed public may also be more likely to accept the Federal land-management actions needed to respond to changing forest conditions. Information on climate change is best conveyed through: the periodic assessments of the Nation's forest resource trends provided by the Forest Service; the Forest Service's National Forest management plans; the Bureau of Land Management resource-management plans; the management statements for each National Park; the results of Forest Service research, inventory, and forest health monitoring; and the cooperative research and extension programs.

POLICY OPTIONS

Potential strategies for adapting to climate change are considered below for the three problems we have identified as being of primary concern: the potential loss of species, uniquely valued forest stands, or entire ecosystems; the increased potential for catastrophic mortality; and the potential for regional or local dislocations in forest-dependent communities.

■ Biodiversity and Forest Loss

Option 6-1: *Enhance forest seed banks and forest genetics research.* A national effort to

[21] Federal forestry research is organized through eight regional USDA Forest Service Research and Experiment Stations and one Forest Products Laboratory.

collect and conserve a wide variety of forest seeds would ensure that the means are available to respond to the potential loss of forest species or populations under climate change. The coordination and cataloging of existing public and private forest seed-storage programs would be a useful first step. Use of the seed bank for restoration will require the development of improved techniques for long-term storage of seeds and large-scale propagation of trees from stored genetic material. Such efforts should most logically be coordinated by the U.S. Department of Agriculture's (USDA's) Forest Service, which already has seed storage, forest nurseries, and forest genetic research programs supporting current planting needs. Congress could fired a National Forest Genetic Resources Program within the Forest Service, providing funds for seed collection, for an expansion of seed-storage facilities, and for associated research needs.

There is currently no national program for forest genetic resource conservation. Current seed-collection activities are uncoordinated and focused on a relatively small number of species (45, 55). The systematic storage of seeds is done primarily for the few species that have high commercial value, such as the pines. Some arboretums, universities, and Forest Service researchers also have limited programs associated with threatened or endangered species or species of particular interest to the researchers. Existing Forest Service seed-storage facilities and nurseries are limited and intended to meet the current regeneration needs of the National Forests. Many of the existing genetic research programs within the Forest Service also have modest seed collections, usually established as the basis for commercial tree-improvement work.

A much broader national program focused on protecting the seeds of most major forest tree species and associated shrubby and herbaceous forest plants may be needed.[22] Maintaining the large quantities of seeds needed for a major replanting would bean unrealistically costly goal. Instead, a useful goal for the seed banks might be to maintain a sufficient variety of seeds that the original genetic diversity of forests could eventually be rebred. The capabilities exist for storing the seeds of the majority of woody species for about 50 years under refrigeration (about 200 of the 270 major tree species) (45). Certain other trees, particularly the white oaks and poplars, have seeds that deteriorate quite rapidly. For these species, conservation in plantations might be considered. From this 'Noah's Ark," the gradual restoration of lost species or forest populations might be attempted, if the need ever arises. The systematic storage of seeds would also prove valuable to commercial tree breeding and for biotechnology efforts in tree improvement.

Seed storage requires refrigerated facilities, with primary and secondary collections. The secondary collections serve as the working collections, with seeds made available for ongoing research and breeding purposes. Working collections could be distributed regionally and coordinated through existing Forest Service Research and Experiment Stations. Distributing seeds regionally allows species to be matched to the areas in which they grow. The primary collections might be located in the USDA's National Seed Laboratory in Fort Collins, Colorado--now used for agricultural-seed storage.[23] Use of these storage facilities and existing databases on stored genetic resources might avoid some duplication of effort. Alternatively, the primary collection could be located in one or more of the same Forest Service facilities used for the secondary collections, taking advantage of staff expertise in tree-seed storage.

Eight Forest Service Research and Experiment Stations currently have genetics research pro-

[22] Eventually, the full 700 native tree species might merit attention, as might seeds of foreign tree species likely to become commercially valuable in the United States.

[23] Use of the Fort Collins facility for tree-seed storage is already authorized.

grams. Three additional programs have been proposed (for Alaska, Hawaii, and Puerto Rico). These 11 programs could serve as homes for the working seed collections-collections made available for ongoing research and breeding—and as expanded centers for forest genetics research. One or two of these programs (e.g., one eastern and one western) might be designated to coordinate the seed-storage program and to serve as primary centers for genetics research. Associated with the genetics research programs might be efforts addressing the genetic distribution of tree species, sampling strategies for seed collection, the sensitivity of trees to climate, large-scale propagation techniques, and cryogenic techniques for improved long-term storage of genetic material.

Seed collections should represent the variety of genotypes for each species. Ideally, a sampling scheme would capture the genetic extremes within the species as well as some intermediate populations. In the absence of knowledge about the genetic distribution, a practical approach is to sample on a geographic grid following Forest Service guidelines already frequently used for seed-collection zones (every 50 to 100 miles, or every 1,000 feet of elevation) (41).[24] A collection could be accumulated over the next decade. Collections could be made on a priority basis. First, those species already at risk or least able to adapt to climate change might be collected. The next priority might be those species of obvious high ecological, economic, or aesthetic value.

Currently, the Forest Service spends about $1.25 million annually on its genetic research programs and tree-improvement programs. It is estimated that a new forest genetic-conservation program would require continued funding of about $5.5 million annually,[25] with an additional $30 million in one-time construction and seed-collection costs.[26] This would include research on genetic diversity and sampling design, construction of new or expanded storage facilities at 11 program centers, maintenance of the seed collection, and establishment of plantations for genetic conservation and continuing seed production. Some funds to support this expanded program of seed storage and genetics research might come from fees charged for access to the working collection by industry or private researchers. Access to an extensive and well-cataloged seed collection would be valuable to industry tree-breeding programs.[27] A fund that draws on Forest Service and Bureau of Land Management revenues, a tax on timber and outdoor recreation products, or existing tariffs on timber products might be other appropriate sources of funds. For example, the Reforestation Trust Fund established in 1980 (P.L. 96-451) drew about $30 million annually from the tariff on timber imports, supporting an expanded reforestation effort in the early 1980s.

Option 6-2: Use *the Experimental Forests for research on adaptation to climate change.* Experimental Forests are established by the chief of the Forest Service to serve as the outdoor laboratories for testing and demonstrating new management techniques (86). Some 60 Experimental Forests are spread across the National Forests, each typically 5,000 to 10,000 acres in size. Research efforts on these Experimental Forests are important in establishing the scientific basis for the management practices that will be applied to public multiple-use forestland in the future.

A new research program in Experimental Forests could be directed toward finding practical techniques for accelerating and improving the adaptation of forests to climate change, with a

24 For a widely dispersed species, this might mean 100 sampling points with 30 to 50 trees sampled at each point, and perhaps 1,000 seeds per tree *(45).*

25 With annual expenses of $2.5 million for research $1 million@ maintain the collections, and $2 million for genetic plantations.

26 S. Krugman, Director, Forest Management Research, USDA Forest Service, personal communication, August 1S93.

27 R. McCullough, Director, Forest Resources Research, Weyerhaeuser Company, personal communication, June 1992,

Species with limited geographical range, such as these redwoods in California, may be lost if climate changes occur too rapidly to allow migration.

focus on techniques appropriate to the multiple-use forest (which may be different than techniques appropriate for single-use plantation forests). Productive research topics might include evaluations of the means and effectiveness of introducing populations into new climatic zones, of unobtrusive silvicultural-management strategies that might improve adaptability to climate change, of the effects of increased species or age-class diversity in promoting forest adaptability, and of strategies to protect existing forests against climate-related threats. The Experimental Forests provide the opportunity for long-term observations of the effectiveness of these management practices in preparing for climate change, and the lessons learned will serve as the basis for future management response on the larger forest.

The Forest Service might also be encouraged to increase the number of Experimental Forests in order to provide greater representation of forest ecosystems and climatic zones. With public forestland seeming less important for timber production, a larger area of the public forest may now be available for research and experimentation purposes-at little cost to the Government. Ideally, Experimental Forests would be widely distributed to represent many of the various forest ecosystems. Currently, these Experimental Forests are not representative of eastern forests, especially in the South, where National Forest holdings are limited. A more representative distribution of eastern forest types could be achieved by adding some areas on military lands or through cooperative arrangements with States and universities."

Research on the Experimental Forests is undertaken by Forest Service research staff and cooperating private researchers. Current annual expenditures on each Experimental Forest average $0.5 million or less, which covers maintenance of roads and structures and on-site expenses of the experimental program.[29] An expanded effort On Experimental Forests would result in an increase in these support costs, but no new research staff would be required. An experimental climate change program, with one or two active projects per forest, could probably be supported with an additional annual appropriation of about $250,000 to $500,000 per forest.[30] Included in this might be a small cooperative grants program to attract university research projects, increasing the pool of new ideas. Some existing Experimental Forests have been so extensively managed already, however, that experiments that require more-natural forest conditions cannot be considered. Any new Experimental Forest would require start-up expenditures for access roads and facilities.

Option 6-3: *Encourage diverse management practices on portions of the public forests as a buffer against climate change. This* option extends the idea of option 6-2, to suggest considering cautious implementation of experimental practices on public multiple-use forests. The Forest Service and BLM could be encouraged to actively hedge against the risk of an uncertain future climate by using different silvicultural and planting practices across the forest and techniques that introduce genetic, species, or age diversity within stands. The diversity in practices, strategies, and species may provide a buffer against the uncertainties of climate change, with some efforts succeeding while others fail.

For example, a mix of different planting practices might be used to help reduce vulnerability to future climate change. A greater variety of species might be planted--either within a single stand or across stands. The effectiveness of using diverse seed sources for plantings could also be considered. It is standard practice now for seeds to be drawn from a variety of local sources that closely match the conditions on the harvested site. It may be appropriate to regenerate some modest proportion of the forest with seeds or seedlings drawn from climate zones that are somewhat warmer than the planting site's.[31] Initial planting densities might also be increased to compensate for the possibility of higher mortality in poorly adapted seedlings (10, 45). These practices all present some risk of failure, but if warming does occur, losses may be less severe than they might have been without the experimental efforts.

A mix of different timber-harvesting strategies offers another way to promote forest diversity. The Forest Service has recently committed itself to an Ecosystem Management approach, under which forests are to be managed with greater sensitivity to the ecological processes of the forest (69). Among the suggestions for management are the 'new forestry' techniques proposed for the Douglas-fir forests of the Pacific Northwest (21). These harvesting techniques create a diverse forest through selective cutting that eventually produces a multiple-aged forest stand. This or other harvest-management strategies designed to promote ecological diversity might be intro-

28 A report prepared for the National Science Foundation in 1977 (32) suggests the need for Experimental Ecological Reserves representing a wide array of ecosystems. That report suggests possible site locations that would add to the coverage of forest ecosystems.

29 S. Krugman, Director, Forest Management Research, USDA Forest Service, personal communication, August 1993.

30 As an upper limit, consider that full utilization of these Experimental Forests would be achieved with an increase of perhaps $1.5 to $2.5 million per forest (S. Krugman, personal communication, August 1993).

31 It is considered preferable to draw seeds from lower elevations than from more southerly sites. -S from more southerly sites are adapted to different day-length regimes (45),

duced in some areas of multiple-use forestland. Harvesting practices designed to achieve a mixture of species and age classes are likely to protect a forest against the spread of insects and fires. At the other extreme, some areas of the forest—perhaps those subject to high risk of pest and fire damage managed with shortened harvest-rotation periods. Shortened rotations are thought to allow faster adaptation to a changing climate because each harvest creates an opportunity to achieve a new stand composition that is better suited to current climatic conditions.[32]

Option 6-4: *Protect highly valued forest sites, The* Federal land-management agencies should identify and evaluate whether there are measures they could take to protect some highly valued or unique forest stands (such as the giant sequoia and redwood stands of California) from loss under climate change. These sites are highly valued because of specific characteristics of the existing forest, which might be threatened by climate change. The decision could be made to protect some of these stands against change or loss, where practical. If conditions allow, this might mean developing irrigation systems and using intensive efforts to control insect and fire threats. Congress may need to be prepared to act quickly in funding protective actions, if they become appropriate.

Option 6-5: *Provide incentives to reduce fragmentation of private forestland.* Fragmentation and loss of private forestland may threaten the ability of forests and forest species to migrate or adapt to changing climate. Some expansion of Federal funding might be considered for existing incentives programs that encourage multiple-use management on private forestland (e.g., the Forest Stewardship and Stewardship Incentive Programs) and the maintenance of forest cover in areas of ecological value threatened by land-use conversion (e.g., the Forest Legacy program). Such funding might come from a reallocation of funds now directed toward providing incentives for enhanced timber production from private lands. Some modifications to the U.S. Tax Code could also be considered to encourage landowners to keep lands in forest cover.

The Forest Legacy program, authorized under the 1990 Farm Bill (the Food, Agriculture, Conservation, and Trade Act, P.L. 101-624), is a conservation-easement program that encourages forest protection in areas of environmental importance and areas threatened by conversion. The program is a cooperative State and Federal effort. Priority is given to protecting areas of high scenic or recreational value; riparian areas; and habitats of particular wildlife, including threatened and endangered species. Property owners are paid in exchange for agreeing to property easements (i.e., restrictions on the deed of ownership) that will ensure continued protection of the resource. Implementation of this program is beginning in six States (New York, New Hampshire, Vermont, Maine, Massachusetts, and Washington) with the development of criteria for potential acquisitions. So far, only 12 tracts have been placed under easement.[33] Other States are considering whether to join the program. Funding was almost $10 million in 1993, but it is expected to be reduced in the 1994 budget.

An advantage of easement programs is that they are cheaper than outright purchase of land. Still, the costs of acquiring easements can be high, including administrative costs of tailoring easements to each property and the costs of monitoring for compliance, in addition to the purchase costs. In areas where development is imminent, the cost of acquiring an easement may be little less than the cost of outright purchase. Easement programs are also somewhat controversial. Because this program will involve only willing sellers, it imposes no unwanted restrictions on use of private property. Still, a program that will create permanent Federal rights restrict-

[32] Edward A. Hansen, USDA Forest Service, personal communication June 1992.

[33] J. Nordin, Cooperative Forestry, USDA Forest Service, personal communication, August 1993.

ing the future use of private property is troublesome to some. The fact that easements can be purchased only from willing sellers also suggests that easement programs alone, although they may be effective at protecting individually valuable pieces of lands, may not be able to stop a general fragmentation of forest holdings.[34]

The Forest Stewardship and Stewardship Incentive Programs, authorized by the 1990 Farm Bill, provide technical assistance and financial support to landowners who wish to manage their forestland to provide multiple-use benefits. Under the Forest Stewardship Program, funds go to the States to cover costs of developing multiple-use management plans for nonindustrial private forestland. These plans encourage management that enhances multiple-use values-such as the productivity of fish and wildlife habitat, water quality, wetlands, or recreational resources-in addition to timber productivity. The declared goal is to enroll 25 million acres in the Forest Stewardship Program by 1995. By 1992, some 3.7 million acres across the country had authorized plans (98). In many States, demand for these stewardship plans is outstripping the State's ability to develop them.[35]

Funding for the cost-sharing Stewardship Incentive Program was about $18 million for 1993. This popular program may encourage landowners to keep their lands in well-maintained forest cover. Congress could provide clearer priorities for which forest areas and what types of activity are to be funded. For example, some funds could be explicitly targeted. Areas identified as having high environmental value and being threatened by conversion, such as those identified under the Forest Legacy Program, might be given high priority. Areas at high risk for fire and insect damage could also be given priority. The extent to which this incentive program can fund the conversion of natural forests to plantation forestry could be clarified by Congress; much of the funding could be reserved for management that maintains a more natural forest cover.

Certainly more controversial than the incentive program would be modifications to the U.S. Tax Code that might encourage protection of forestlands.[36] One possible modification is to reduce or eliminate the capital gains tax due on receipts from the sale of conservation easements. This would tend to make landowners more willing to agree to the sale of an easement. On the other hand, this might be viewed as a budget maneuver that results in foregone tax revenues instead of higher expenditures on easements. Another possible approach is to tax inheritance of land at fair market value, rather than at current use value, unless the new owners agree not to develop the land for some specified period.[37] This would provide a strong incentive not to break up forested estates on the death of the previous owner. This would have some effect in preserving very large forested estates.

Threats of Catastrophic Mortality

Prudent management, in view of the risk of climate change, would anticipate an increased probability of weather-related stresses and increased forest mortality. Not all increases in forest mortality will require intervention. Indeed, the opening of a forest that results from fires and insect damage may speed the regrowth of better-adapted species in the natural forest, much as harvesting and thinning do. However, large-scale mortality poses a threat to forest values, and places adjacent properties at increased risk to

[34] A detailed discussion of the benefits and shortcomings of easement programs can be found in the Northern *Forest* Lands study, *which* addressed ways to slow forest fragmentation in the northeastern united States (25).

[35] D. Gehring, Cooperative Forestry, USDA Forest Service, personal communication, August 1993.

[36] Each of these possibilities is analyzed in more detail in the N- Forest Lands Study (25).

[37] Currently, land is taxed at current use value rather than at fair market value, although adjustment cannot reduce the value of the estate by more than $750,000.

damage from spreading fires and pest infestations.

Option **6-6: Use** *existing monitoring and inventorying efforts to identify causes and effects offorest decline.* Monitoring strategies are essential for determiningg changes or trends in forest systems and in the environmental variables influencing these systems. To be useful for management decisions, such monitoring programs must be maintained over long periods and their design should be scientifically based so that the causes of forest change can be determined. The recently established Forest Health Monitoring Program could be provided with secure and long-term funding to ensure its usefulness and to sustain cooperation with the States.

Congress directed the Forest Service to initiate a program to monitor the health of the Nation's forests about 5 years ago through the Forest Ecosystem and Atmospheric Pollution Act of 1988 (P.L. 100-521). The act calls on the Forest Service to conduct the surveys necessary to monitor long-term trends in the health and productivity of domestic forest ecosystems. A new national initiative, the Forest Health Monitoring Program, a cooperative effort of the USDA Forest Service, the States, and the U.S. Environmental Protection Agency (EPA), has begun under this forest health-monitoring authority (97).[38] The program has ongoing efforts in 12 eastern States and initial efforts in two western States. Further expansion is planned, as budgets allow.[39] Participating States share in the costs of the surveys. The frequency and scope of the surveys planned under this program are designed to detect unexpected changes in forest conditions and to help correlate these changes with potential stressors. The Forest Health Monitoring Program provides frequent monitoring at a set of forest inventory sites, tracking soil, air, water, climate, and land-use conditions-along with details on vegetation and forest pests—at frequent intervals. If significant changes in forest conditions are found, intensive research efforts will be directed at determining specific causes of decline.

In a related activity, the Forest Service conducts periodic inventories of timber resources in all States, under the authority of the Forest and Rangeland Renewable Resource Planning Act (RPA) of 1974 (P.L. 93-378). These infrequent inventories (done approximately every 10 to 15 years) detect major trends in forest mortality and vigor, but provide little understanding of cause and effect. The Forest Service also makes aerial and ground surveys of existing pest damage on Federal forestland. With Federal assistance, State forestry agencies provide similar forest health surveys of State and private forestland. These surveys provide the support for ongoing pest-management activity but, again, provide little information on the causes of the existing pest problems. These inventories and surveys could be required to include analyses of potential causes of observed trends.

Option 6-7: *Establish criteria for intervention in order to protect or restore forest health through a forest health bill.* Congress could establish criteria-through a forest health bill—for prompt intervention that would guard against threats of catastrophic mortality or that would restore forests tier large-scale mortality and decline. Given the emotional level of debate that often accompanies public forest management, it can be difficult to make timely responses to major declines. The congressional debate on a forest health bill in the 102d Congress highlights the controversy that forest management can arouse; efforts to ease restrictions on salvage harvests in

38 The Forest Health Monitoring Program also serves as one component of the Environmental Monitoring and Assessment Program (EMAP), an interagency program coordinated by EPA and designed to monitor the health of the Nation's ecological resources (106). See chapter 6.

39 Annual Federal funding to the Forest Service has been flat at about $14 million, H. F. Kaiser, Director, Forest Inventory Staff, USDA Forest Service, personal communication% August 1993.

the drought-stricken interior Pacific Northwest forests became entwined with the broader and very contentious debate over old-growth-forest management in 1992 (109). Climate change, however, may increase the urgency for intervention designed to protect forest resources. Policies should be in place that set appropriate criteria for salvage harvests (i.e., the removal of dead, damaged, or insect-infested trees), for the use of silvicultural management practices (e.g., thinnings) to protect against threats to forest health, for aggressive insect and fire prevention and control, and for restoration activities after forest decline.

Congress might request that the Forest Service and BLM forma policy-review group made up of outside academics and Federal forestry officials. The group could consider appropriate responses to the threat of large-scale forest decline and criteria that should be met before such responses are undertaken. These criteria would have to take into account the environmental services of the forest, as well as the financial interest in the timber resource. Once such criteria have been determined, Congress could again consider a forest health bill that would help streamline the funding process and the procedures for undertaking actions appropriate for maintaining forest health.

A new forest health bill could allow for the declaration of temporary forest health emergencies, under which the Secretary of Agriculture and the Secretary of the Interior could accelerate actions to protector restore forest health, as long as these actions are consistent with established standards and guidelines for protecting of all forest values. During the period of emergency, funds available for forest salvage, timber-sale activities, reforestation, and insect or fire management might be reallocated to forest health projects. This flexibility in funding would allow for prompt response. A salvage fired, comparable to that now available to the Forest Service, should be created for BLM. The provisions of the Forest” Service salvage and reforestation funds could be amended to allow the use of those funds in efforts to restore or protect forest health. Procedures to expedite the public review and appeals processes, consistent with forest management and national environmental laws, might be considered.

Particular attention should be paid to establishing the criteria for treatments in existing roadless areas and reserved forestland. Management standards and guidelines may be needed to ensure that salvage harvests do not open roadless areas to future timber management or lead to higher levels of timber harvests than are called for in current forest plans. On the other hand, certain policies restricting management activities may need to be reconsidered in light of climate change. For example, currently, the National Park Service controls only introduced pests (see ch. 5). Under climate change, with changed dynamics of the natural pest populations (see ch. 2), controlling only “exotic” species may prove unwise. There is a risk that extensive fires and pest infestations will increase in unmanaged forestland.

Option 6-8: *Increase fire- and pest-prevention activities.* With climate change likely to increase the risk of forest loss to fire and pests, Congress may consider funding increased prevention activities in order to reduce the likelihood of high future costs of fire suppression and pest control. Consideration should be given to promoting a balanced and flexible program that promotes the general health of the forest, allowing for funding of silvicultural activities as well as the more traditional elements of fire and pest management. Appropriate silvicultural practices can reduce the susceptibility of forests to fire and pest risks.

If climate change kills trees, the result will be a buildup of dead and downed wood that may lead to damaging forest fires. A reduction in fire risk can be accomplished through fuel *management* (i.e., removal of fallen logs and dead and dying trees)--with prescribed burns or mechanical removal of excessive fuels-and through thinnings that reduce forest density and improve the vigor of remaining trees. A National Fire Management Policy Review Team, established by the Secretaries of Agriculture and Interior, recently recommended substantial increases in funds and personnel to deal with existing hazards from fuel buildup (101, 107, 108). The risks associated with climate change may strengthen this call for funding preventative activities that reduce the fuel hazards on forestland.

Prescribed fire is a practice by which fire is started or allowed to burn under carefully controlled conditions. The goal is the removal of fuels before they accumulate and lead to intense and uncontrollable fires. Although the use of prescribed fire is broadly accepted as beneficial ecologically (101), it can be costly and controversial. Public sentiments aroused by runaway fires and the associated property losses have made the use of prescribed fire difficult.[40] The limited humanpower available for setting and controlling the prescribed fires and complying with the requirements of the Clean Air Act limit their greater use. Although cautious use of controlled fire is possible in areas with heavy fuel accumulation, more expensive mechanical means of removing brush and fuels are often also needed. Salvage harvesting, the removal of dead or dying trees, can also be useful in reducing current fire risks.

Forest thinning can be effective in reducing the long-term potential for future forest mortality. Thinning a forest reduces moisture demands on remaining trees. With less moisture stress, mortality from the secondary threats of pests and frees can be reduced(51). The most striking example of the benefits of thinning can be found in the drought-stricken regions of the West, After several successive years of drought in Idaho and eastern Oregon, mortality rates on some National Forest lands have been extraordinarily high, with much of the forest lost (see box 6-E). On adjacent, thinned industry lands, the forest remains healthy .[41] Extensive thinning is now being undertaken on some of the drought-stricken National Forests of Idaho (49). When the wood from thinning and salvage cutting can be marketed,[42] these activities can often be cost-effective ways of reducing the threat of large forest fires. However, silvicultural management is not appropriate under all conditions. Thinning, for example, can sometimes lead to excessive damage to residual trees. Salvage harvesting— like any large-scale harvesting activity--can lead to environmental problems (e.g., erosion and watershed damage) and is generally not appropriate where harvesting would otherwise be excluded.

Long-term reductions in forest pest problems can be accomplished through integrated pest management programs, which combine monitoring, thinning to control stand density and species mix, quick salvage or removal of infested stands, and suppression through pesticides and fungicides. Just as it enhances fire prevention, improving the general health of the forest through silvicultural activity may be the best way to reduce the likelihood of future mortality caused by pests.

In 1992, the Forest Service received about $13 million for fuel management, that is, for prescribed fires and mechanical removal of downed Wood.[43] In contrast, about $175 million was allocated for the other elements of fire protection--equipment and personnel needed to maintain readiness for firefighting-while roughly

40 The reaction to the Yellowstone fires of 1988 illustrates the problems of applying prescribed burns (101). Some of these fires, which *eventually* burned *740,000* acres of the Park, were initially allowed to bum as prescribed fins. It is doubtful, however, whether more rapid suppression of those fires would have done much to limit the overall damage (101; see box 5-I).

41 D.F. Smith, Vice President, Timberland Resources, Boise-Cascade Corporation, personal communication and videotape, June 1992.

42 Decay can fairly rapidly reduce the potential sale value of wood once a tree has died. Within 2 years of death, much of the economic value of the wood is lost.

43 About $50 million in brush-disposal funds-deposits by timber purchasers fOr cleanup after sales—can also be considered support for fuel-management activity, although this money does not help address existing fuel buildup.

$400 million (including $300 million in emergency appropriations) went to firefighting itself. Increasing interest in the ecological benefits of prescribed fire and modifications in the Forest Service's fire-management-planning system to better incorporate the benefits of fuel management are thought likely to lead to an increase in the relative emphasis the Forest Service will place on fuel management in future budget requests.[44] Climate change would seem to add to the reasons for supporting such a shift in fire funding priorities.

On Forest Service lands, special funding for salvage harvests is provided through monies drawn from timber-sale revenues, making it relatively easy to undertake salvage harvests as needed. Thinnings are usually undertaken for timber management reasons. There may be increasing demands to fund thinning programs that promote general forest health-as has already happened in the National Forests of Idaho and eastern Oregon-rather than explicitly for timber management. Support for thinning activities may be increasingly appropriate, as climate change poses a threat to future forest health.

Option 6-9: *Ensure that potential restrictions on below-cost sales do not prohibit activities needed to maintain forest health.* Much of the timber supplied from National Forests has brought in less in revenues than it cost to put the timber up for sale (114). It appears that below-cost sales on National Forests may be increasingly restricted (72). Congress may wish to ensure that timber-harvesting or thinning activities necessary to maintain the health of National Forests (e.g., to counteract damage from insects, disease, and fires) are not made impossible by legislative action designed to end below-cost sales.

Option 6-10: *Provide incentives and information to private forest owners to reduce hazards and to improve forest health. The* Forest Service offers technical and financial assistance to State and private forest owners through a variety of programs aimed at protecting and improving the management of forestland. Several cooperative programs in hazard control through fire protection and insect suppression are in place and may become increasingly valuable if climate change threats materialize.[45] Other useful programs are aimed at reducing exposure to risk.

Under authority of the Cooperative Forestry Assistance Act of 1978 (P.L. 95-313), as amended by the 1990 Farm Bill (P.L. 101-624), the Forestry Incentives Program (FIP) and various other forestry assistance programs offer financial support to owners of small, private forests. Funds under the FIP are allocated on the basis of potential improvement in commercial timber production, with much of the money going toward planting pine forests. This program is now scheduled to end in 1995. The amendments to the Cooperative Forestry Assistance Act have established broader goals for cooperative support, including increased emphasis on the environmental and multiple-use services of private lands. No specific program, however, targets support to private landowners to promote activities that might protect forest health.[46] A forest health incentives program might be considered, which would target funds to forest landowners in areas where there are high risks of insect and fire damage, encouraging silvicultural activity to improve the health of private forestland.

[44] D. Trysdale, Fire and Aviation Management Staff, USDA Forest Service, personal communication August 1993.

45 The annual report of the Forest Service (98) describes the many State and private forestry programs.

[46] This goal would be compatible with the broader criteria for support under the Forest Stewardship Program, however. support is provided through the States for pest surveys, pesticide applications, and technical information services.

Among the greatest costs of wildfires are the losses of property and life in buildings at the edge of forests.[47] The issues related to the high costs these homeowners impose on the general taxpayer for firefighting activity will certainly become more prominent as development adjacent to forests increases or if fire becomes more prevalent. There is perhaps little direct Federal leverage to discourage owners from building in high-fire-hazard zones. However, the Federal Government can encourage appropriate building practices for structures built near forests by supporting information and education programs for homeowners in such areas. The Forest Service's Urban/Wildland Fire Protection Initiative disseminates information on measures that homeowners can take to protect against forest-fire risks. Such programs should be continued.

Economic Dislocations

The timber industry will inevitably move from regions where relative profitability has declined under climate change. Such movements in the location of the forest industry could result in the abandonment of forest dependent local communities. If rapid or unexpected, dislocations of this sort can be costly. Although little can be done to stop the movement of industry from less productive regions, there may be options that would help reduce the likelihood of economic disruptions.

One approach is to increase the flexibility of the timber industry and the diversity of the economy in forest-dependent communities. That is, increase the ability of communities to adapt to changing forest conditions by expanding the technologies for using forest products and services. A second approach is to provide accurate information about the risks and uncertainties that climate change may pose for forests and timber supplies. The industry and communities that depend on forests might then have time to respond and to lessen the potential for sudden economic losses.

Option 6-11: *Incorporate climate change scenarios into forest plans and assessments. Ensure* that National Forest plans and BLM resource plans provide one or more climate change scenarios that project timber supplies and resource trends under potential climate changes. The plans should address the potential stresses that climate change poses to the forest resource. However, forest plans are already deficient in addressing the uncertainties associated with current stresses that lead to fire and insect damage (91).

The Forest Service has expressed some reluctance to use specific projections for a changing climate in its National Forest plans because of doubts about the precise nature of climate change in any specific location. Although understandable, this reluctance may be misguided because it is precisely this uncertainty that should be conveyed to the public. The timber industry, which depends on Federal timber sales, and dependent timber communities may be better able to take appropriate precautions in a timely manner if they are made aware of the uncertainties in future timber supplies.

No new legislative authority is needed for the land-management agencies to begin addressing the uncertainties that climate change presents. With previous encouragement from Congress, the Forest Service's next RPA assessment (in preparation for the 1995 update) is considering climate change scenarios in its national projections of future timber supply trends.[48] More encouragement may be needed before similar efforts are made at the level of individual forest plans.

Option 6-12: *Eliminate the even-flow-harvest requirement of the National Forest Management Act (NFMA). The NFMA*, Section 13(a), requires that timber sales from National Forests generally be limited to a level that can be sustained in

47 Reference 13 offers some thoughts on policies for dealing with fire risks and the urban-forest interface.

48 Linda Joyce, USDA Forest Service, personal communication, June 1993. Initial efforts apparently have not addressed the potential threats that climate change poses for existing forest.

perpetuity, a requirement usually known as *non-declining even flow. This* well-intentioned provision was meant to help maintain stability in local communities and to avoid biologically damaging rates of harvest. The policy as applied has not produced the intended results. Instead, it creates a false promise of sustained timber supplies, distorting the planning decisions of timber industries and workers. Perversely, it has also tended to encourage unsustainable forestry practices on Federal forestland, increasing the land area on which active timber management is practiced and encouraging intensification of management on poorer-quality lands. These consequences add to the costs and reduce the area left as natural forest (7, 94).

Under climate change, with the possibility of a declining forest, the even-flow policy will have further undesirable effects. The policy creates a strong incentive for Forest Service managers to ignore climate change considerations in the NFMA planning process. Under the nondeclining-even-flow constraint, any expected reduction in the future timber productivity of the forest would require an immediate reduction in current allowable timber sales. Thus, the acceptance of the possibility of negative effects of climate could lead to disruptions in the local timber industry and communities-a result the forest managers would prefer to avoid. A more gradual decrease in harvest levels would be preferable. Federal timber sales could be based on supply-and-demand conditions, subject to reasonable market tests of profitability and to the requirement of maintaining the multiple-use and environmental services of the overall forest.

Option 6-13: *Increase flexibility in the timber industry.* Rapid climate change may result in changes in the quality or type of timber available for harvesting on the Nation's forestland. There may be changes in the species available for harvest; younger trees might be harvested if climate risks discourage long-rotation forestry and damage existing older stands; and there may be increases in the availability of low-quality and **salvaged** logs. Research directed at increasing the flexibility with which industry can adapt to these potential changes in timber supplies may help reduce the costs of climate change. This increase in flexibility might be accomplished through research and product development that allows the timber industry to use more varied log sizes, log qualities, and tree species. Although these areas of research and development are already of active interest, many think that forest-products research has been greatly underfunded (54, 99). In real dollars, Federal funding of forestry research has declined by more than 10 percent over the past decade (99) despite the high economic returns of this research (28).

Option 6-14: *Increase flexibility in forest-dependent communities.* Forest Service programs to diversify within forest-dependent rural communities were authorized by Title 23 of the 1990 Farm Bill, the National Forest-Dependent Rural Communities Economic Diversification Act of 1990 (P.L. 101-624). Under this authority, the Forest Service has begun to play a role in implementing the President's initiative on rural development. The existing efforts include technical assistance and small cost-sharing programs to help improve the stability of rural communities through diversification away from resource-dependent industry and through projects that promote diversification within the wood-products industry. Funding has been modest. For example, about $0.5 million annually is available in Economic Diversification Grants to assist communities in developing plans for attracting new industries that might reduce dependence on timber. There are other specially funded programs, such as those that assist economically distressed communities in the Pacific Northwest, an initiative that encourages the use of wood in building bridges, and demonstration projects of uses of waste wood, including recycling. Climate changes may increase the importance of programs designed to diversify forest-dependent communities, but it is still unclear how successful these effort can be.

An opportunity may exist *to turn* salvaged and thinned wood into a useful resource. The Forest Service should be encouraged to expand efforts, through its Forest Products Research and Cooperative Assistance Programs, to develop and promote wood-product technologies that use salvaged wood. Rural development grants could be given to identify and encourage local industries to create highly valued products from these low-quality wood resources. The risks associated with such strategies include the perception that subsidized industries in one region are unfairly competing against existing similar industries elsewhere. The stability of supply is critical; industry is unlikely to become established where the supply is erratic.

FIRST STEPS

Although all of the options presented in the preceding section could be considered, not all are equally feasible and not all are equally appropriate as immediate responses to the threat of climate change. Given the limited money available to fund programs and the poor level of scientific understanding of impacts of climate change on forests, the following subset of policies have been identified as the “first steps” Congress could take. Initiating all of them now is justifiable because of current concerns about climate change. By beginning with this package, the Nation can position itself t{. respond to the effects of climate change on both timber and nontimber forests. Some of these options must begin today because of existing problems (such as fire, pests, and drought) that will be exacerbated by climate change or because current programs are already wanting. Others must begin today because it will be years before the process can be completed (such as developing a seed bank and understanding how to facilitate migration). The options listed below were chosen because they meet two criteria: they reduce vulnerability to climate change, and there is a clear advantage to acting now.

- **Establish an expanded forest seed-bank program.** A National effort in the conservation of forest seeds would provide an opportunity to respond to the potential for loss of genetic diversity in the forest resource under climate change. There is currently no national forest-seed conservation program. An appropriate goal for such a program would be to maintain sufficient seed variety, or other genetic material, so that much of the original diversity of the Nation’s forests could eventually be restored.

A forest genetics conservation program would require facilities for seed storage. Primary storage facilities would provide for safekeeping; secondary collections would provide working access to seeds and security through redundancy in storage. Working collections could be based at regional centers for forest genetics, such as those now located at several Forest Service Research and Experiment Stations. The primary collection could be maintained at those same facilities or at the existing USDA agricultural seed storage facility in Fort Collins, Colorado. Associated with the working collections should be a research program addressing issues related to seed collection, storage, large-scale propagation, and climate sensitivity of forest trees.

To accomplish these goals, Congress could authorize and fund a National Forest Genetic Resources Program within the Forest Service, providing funds for the construction and operation of storage facilities needed for the seed collections, for the forest genetics research program, and for the establishment of plantations to be used for continuing seed production. Funding is estimated to require about $5.5 million annually, plus a one-time expense of about $30 million for construction. Such a program could be partially supported through fees for private access to the seed collection.

- **Prepare to respond to major forest declines. Increased risk** of fires and insect damage may result under a warmer climate. The relative value of preventive activities that reduce risk and the need for prompt intervention to protect forest resources may increase. Because of the need for prompt action and because of the contentiousness that often accompanies forest management, policy rules for salvage harvesting, pest-control activity, and silvicultural management to reduce forest health risks are best established before they are needed.

  Congress could provide a forest health bill that would establish criteria that would allow prompt action to protect against threats of catastrophic mortality or to restore forests after large-scale mortality and decline. Such a bill might allow for the declaration of temporary forest health emergencies, under which accelerated actions to protect or restore forest health would be authorized-as long as these actions were consistent with established standards for protection of all forest values. A policy-review group made up of outside academics, representatives of interest groups, and Federal forestry personnel could develop criteria for undertaking actions to stem forest decline. During the period of emergency, funds available for forest salvage, timber-sale activity, reforestation, and insect or fire management could be freely reallocated to forest health projects, allowing a prompt response. In conjunction with this bill, Congress should be prepared to increase funding for forest health maintenance and for activities that reduce potential fire hazards (e.g., removing fuels and thinning the stands at risk); such efforts might reduce the likelihood of much greater future costs.

  Prepare for a forest-managernent response to climate change. A changing climate may eventually require innovations in forest-management and planting practices. Experimental efforts will be important in establishing a scientific basis for any necessary changes to future-management practices that might later be applied to public multiple-use forestland. Congress could support a program of research on the Forest Service's Experimental Forests, or other research facilities, to address adaptation to climate change. The Experimental Forests are in place and designated as the outdoor laboratory for evaluating forestry practices. The research could be directed toward finding practical and environmentally appropriate techniques for managing the public forests that will help buffer them or help them adapt to a changing climate. Funds would be necessary to support the cost of managing the forests. Some funds might be allocated on a competitive basis to support experiments suggested by university and other private forestry researchers, helping ensure a creative pool of ideas.

- **Improve incentives for maintaining and protecting private forestland.** The Federal Government controls only about one-quarter of the Nation's forestland. In the East especially, where Federal holdings are limited, efforts at supporting the protection of private forestland may take on increased importance. The Federal Government will have to use incentives, disincentives, and cooperative approaches to management to promote the health and productivity of this forestland.

  Existing programs under the Cooperative Forestry Assistance Act as amended by the 1990 farm bill provide cost-sharing assistance to owners of small, private forests. Traditional forest-support programs (e.g., the Forestry Incentives Program) targeted funds on the basis of potential gains in timber supply. The support programs could be modified to target money to: 1) areas at high risk of catastrophic insect and fire damage, encouraging silvicultural activity to maintain the health of the private forestland, and 2) activities that prevent fragmentation and further loss of scarce or ecologically valuable forest types. Expanding the role of the Forest Stewardship and Forest Legacy Programs, and reducing support for commercial forestry under the Forestry Incentives Program might promote better protection on private forestland. The Forest Stewardship Program could remodified to provide clearer funding priorities, thus ensuring that some funds are targeted to the areas identified above.

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FORESTS-FIRST STEPS

- **Establish an expanded forest seed-bank program**
  - -Establish a national program in forest seed conservation to help preserve the diversity of our forests.
  - -Fund a National Forest Genetic Resources Program within the USDA Forest Service, providing funds for storage, seed collection, and research.
  - --Establish working collections at regional centers for forest genetics (e.g., Forest Service Experiment Stations).
- **Prepare to respond to major forest declines**
  - —Establish criteria for prompt intervention in the event of large-scale mortality or decline through a new Forest Health Bill.
  - -initiate a policy review group to develop standards for undertaking actions to stem forest decline.
  - —Allow reallocation of funds (forest salvage, timber sale activity, reforestation, and insect or fire management) for prompt response in times of forest health emergency.
- **Prepare for a forest-management response to climate change**
  - -Fund research on the USDA experimental forests to find practical and environmentally appropriate techniques to heip forests adapt to a changing climate.
- **Improve incentives for maintaining and protecting private forestland**
  - —Reorient the Forestry incentives Program away from its current focus on timber production to forest health.
  - —Clarify the funding priorities of the Forest Stewardship Program to target areas of high environmental value and promote natural forest cover.

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Appendix B: Acknowledgments

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