Forests 6

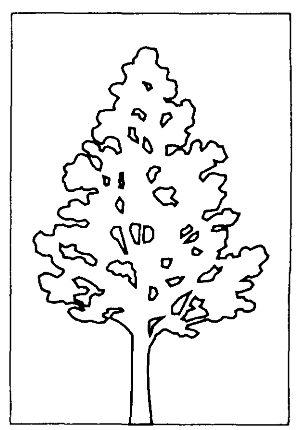
Status
- Currently stable resource.
- Significant area of public forest—with increasing limits on *timber* management.

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

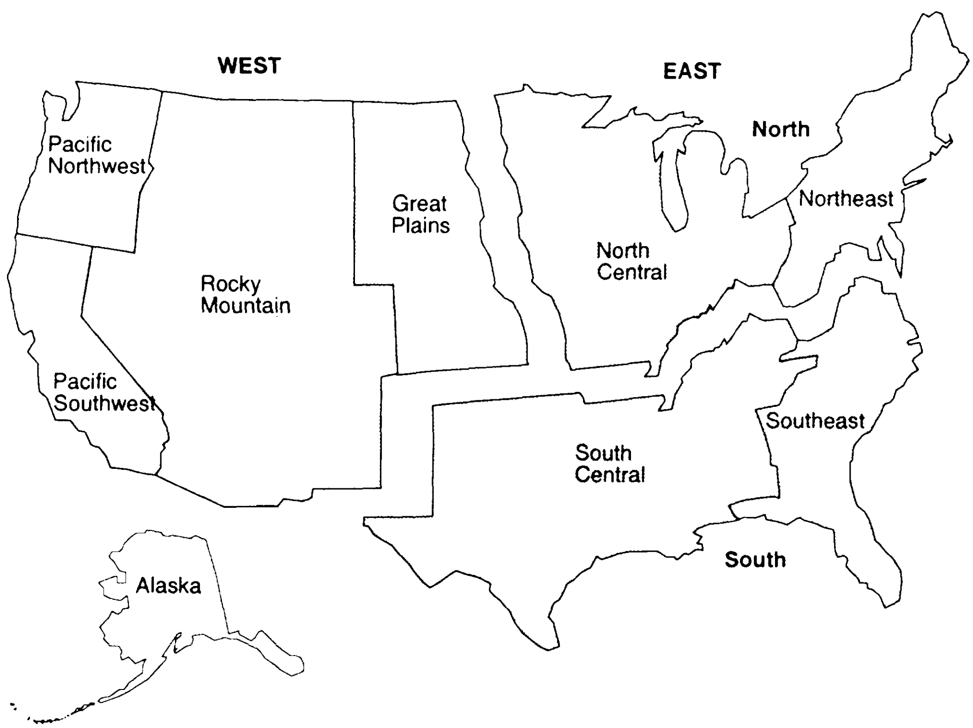
Forests dominate the landscape in much of the United States. They cover roughly one-third (731 million acres, or 292 million hectares)[2] of the Nation's land area and are found in all 50 States (90).[3] These forests are enormously variable, ranging from the sparse scrub of the arid interior West to 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



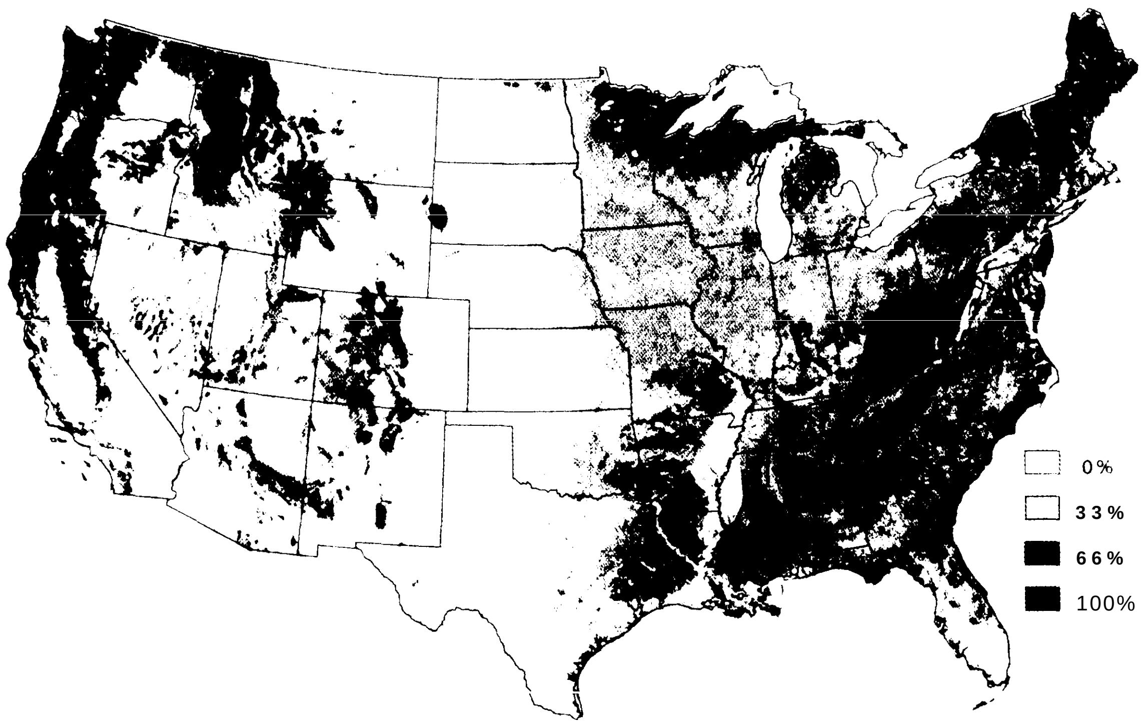
SOURCE: U.S. Department of Agriculture, Forest Service, *An Analysis of the Land Base Situation in the United States: 1989-2040*, General Technical Report RM-181 (Washington, DC: USDA, Forest Service, 1989).

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.

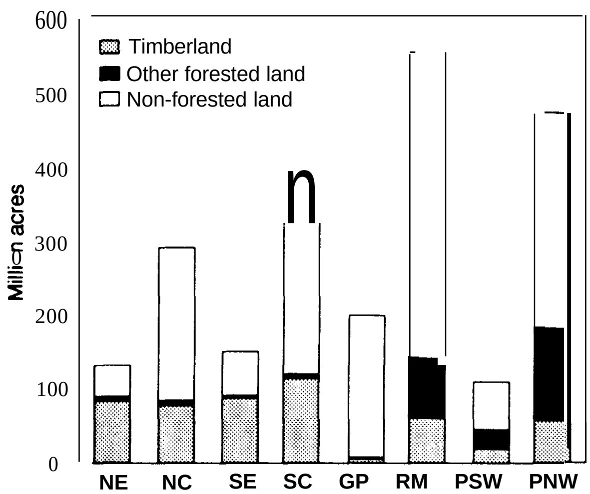
The biodiversity of our forests is a rather different type of value. There are roughly 700 native tree species in the continental United States (44). Some 300 are large tree species that have significant value for current or potential commercial use or for their aesthetic value. Of these, perhaps less 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-l—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
Pesticides	sequestration

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

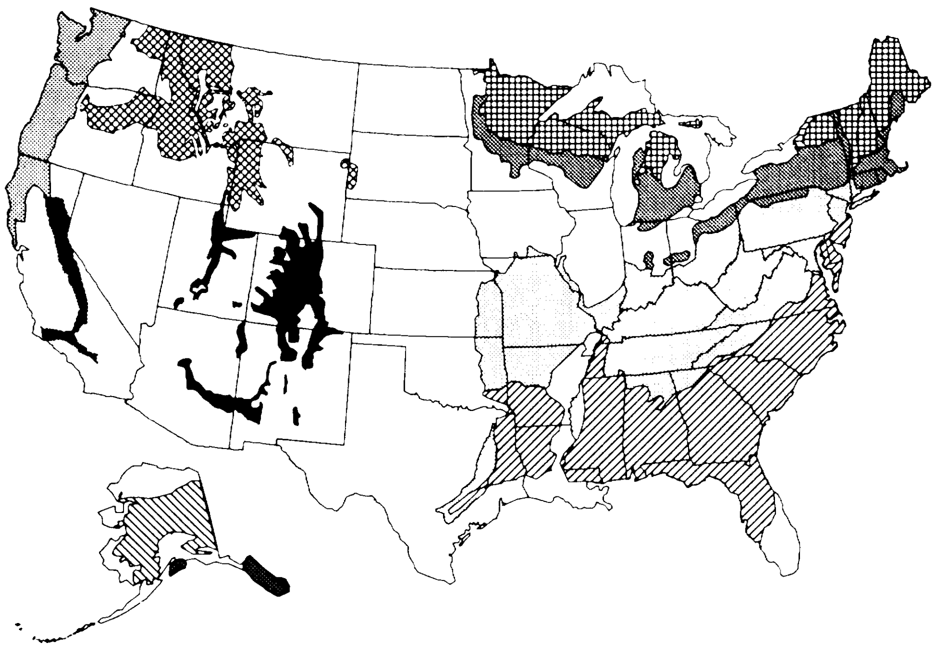
The Forest Service also classifies forests of similar character into *major forest types* (87). These types are most generally described as belonging to one of two broad classes: the *softwoods,* which include needle-leafed conifers such as the pines and firs, and the *hardwoods,* which are broadleafed 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

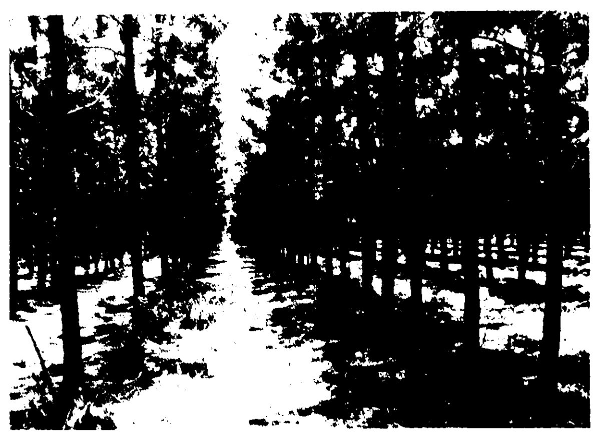


SOURCE: Office of Technology Assessment, 1993 adapted from J. Smith and D. Tirpack, ***The Potential Effects of Global Climate Change on the United States*** (Washington, DC: U.S. Environmental Protection Agency, 1989).

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.

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



USDA FOREST SERVICE

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.*

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
		Hemlock-sitka spruce	11
Total	95	Larch	3
		Redwood	1
Hardwood types		Other western softwoods	1
Oak-hickory	118		
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.

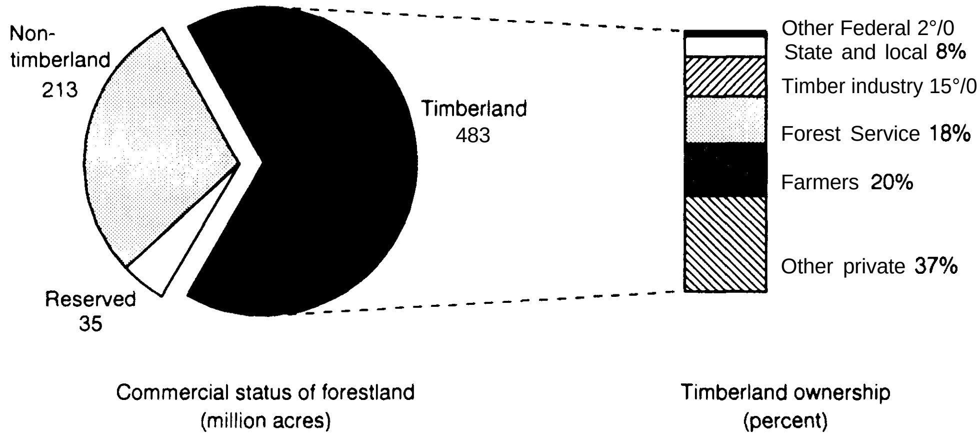
The western softwood forests—The western forests are primarily softwoods. ***Ponderosa pine*** forests are found throughout California, the Rocky Mountains, the Southwest, and east of the Cascades in the Pacific Northwest. In drier regions, ponderosa pine is usually the first forest ecosystem found above 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).

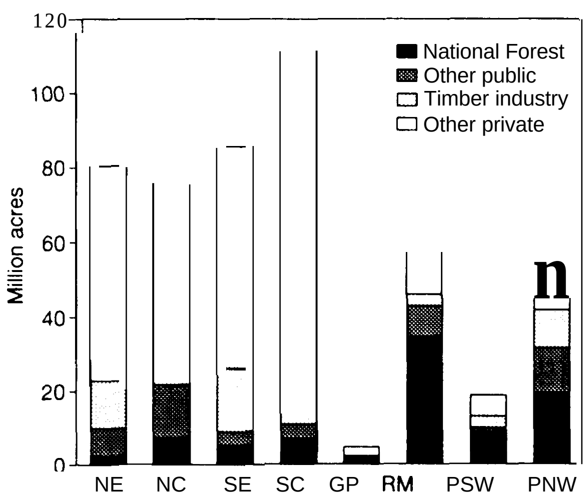
Figure 6-5-Status of U.S. Forestland and Distribution of Timberland Ownership, 1967



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.

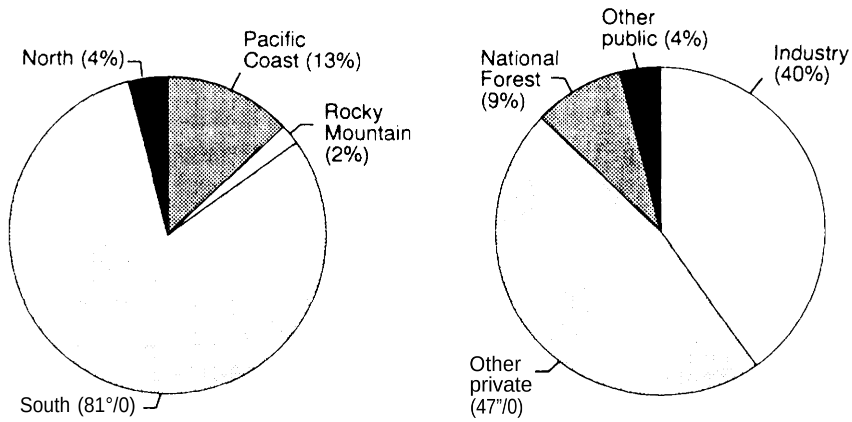
SOURCE: K.L. Waddell, D.D. Oswald, and D.S. Powell, *Forest Statistics of the United States, 1987*, Resource Bulletin PNW-RB-168 (Portland, OR: USDA, Forest Service, Pacific Northwest Research Station, 1989).

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

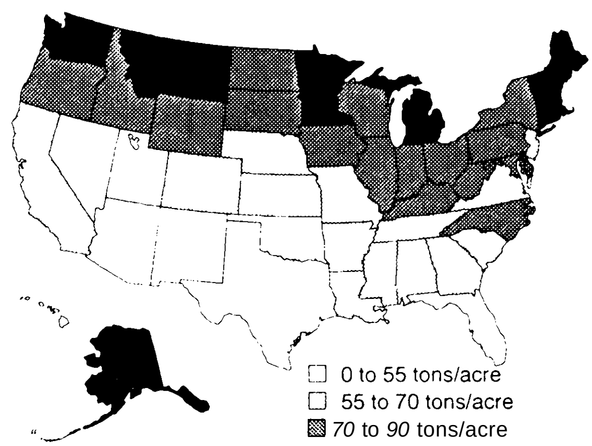
Management intensity varies across the National Forest lands. Except for the management of wilderness lands, National Forest management must reflect a concern for the multiple uses-for timber, recreation, wildlife, rangeland, and watershed-and for the long-run sustainability of the forest. The Forest 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).

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).

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.

[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 all forestland 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 darnage.

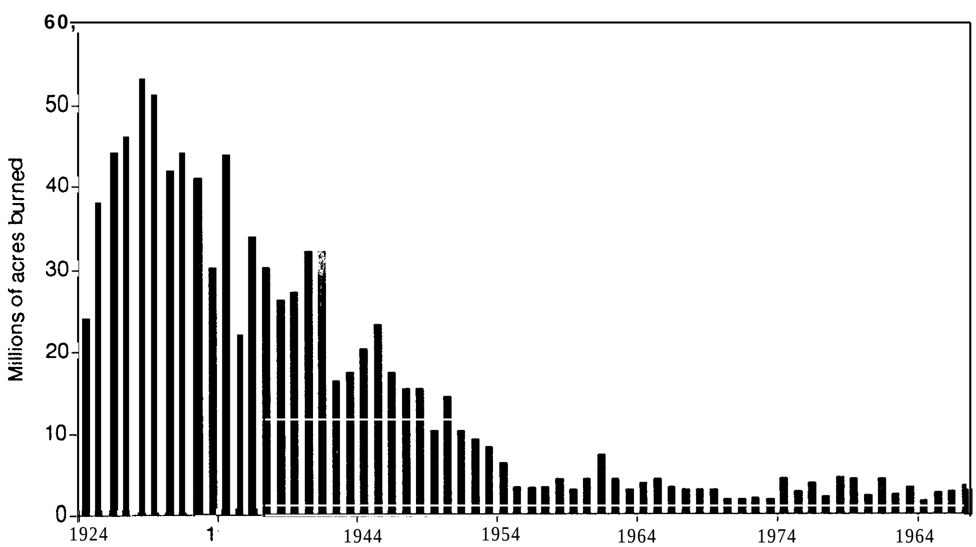
Salvage harvests are another proposed solution supported by the timber and forest products industries. Diseased timber is only good for commercial use up to 2 years after it dies. Salvage harvests **would** “salvage” some of this revenue, reduce fuel loads, and provide local jobs. In addition, the thinned 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).

USDA FOREST SERVICE

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.

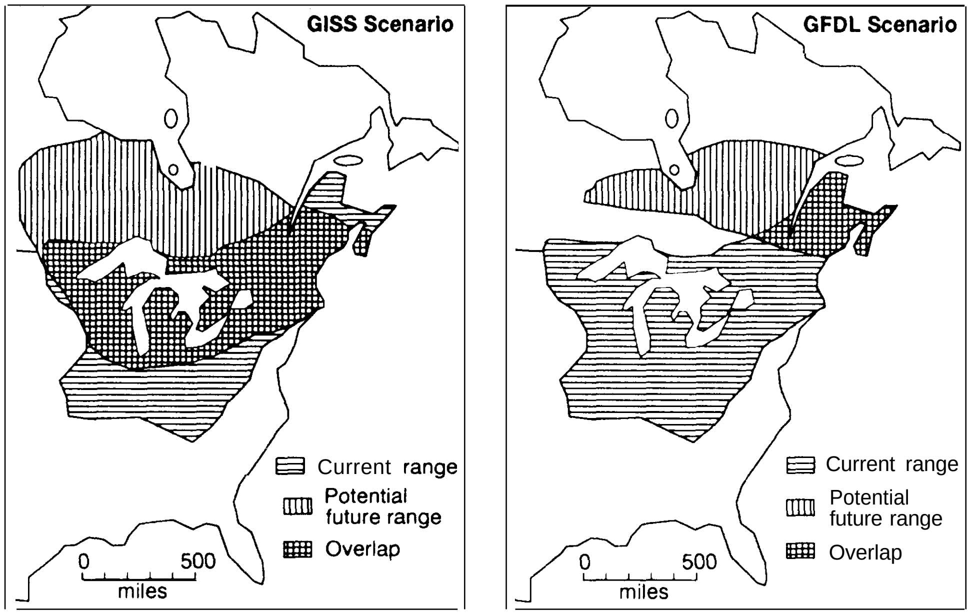
Various methods have been used to predict long-term forest responses to altered climate. Some researchers have attempted to relate climatic requirements of individual tree species to the conditions thought to be likely under a future climate.[11] 0thers have looked at historical changes in vegetation-those 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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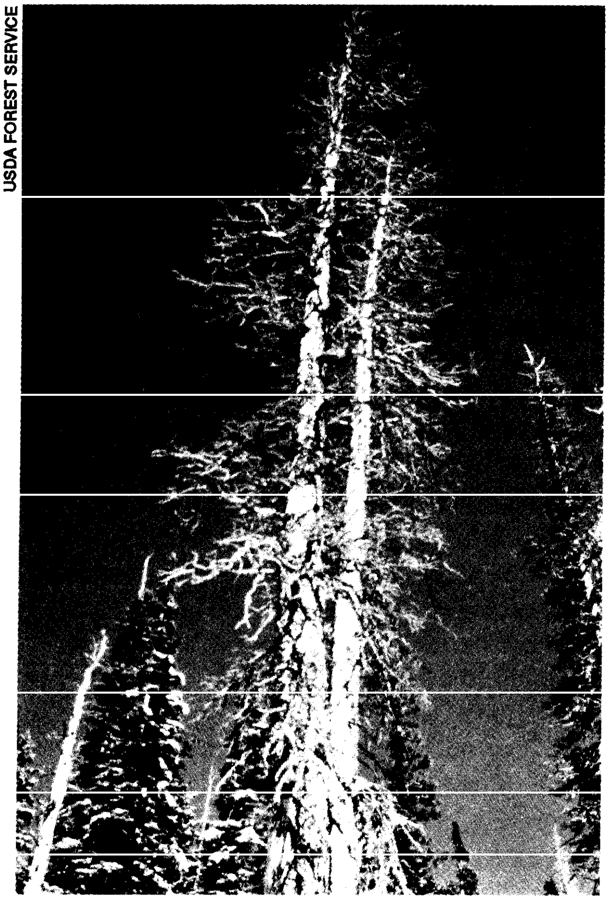


Drought-damaged trees in Colorado. Warmer climate may increase forest mortality from climate-related stresses such as drought, insects, and disease.

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 CO_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 upslope 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 BiIl (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.

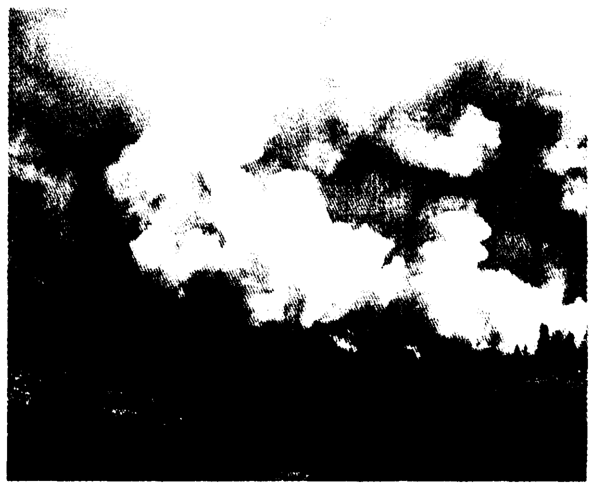
The management approach used on Federal forestland ranges from preserving natural systems to the moderately active timber management found on some multiple-use forests (see box 6-C). Forestland within the wilderness reserve system is by law off limits to active timber management. Within the National 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-

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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

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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 W93.

[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 determinin g 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 Plannin g 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.

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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