FOREST ECOSYSTEMS

Forests, woodlands, and scattered trees have provided humans with shelter, food, fuel, medicines, building materials, and clean water throughout recorded history. In recent decades they have become a source of new goods and services including pharmaceuticals, industrial raw materials, personal care products, recreation, and tourism. Forests regulate freshwater quality by slowing soil erosion and filtering pollutants, and they help to regulate the timing and quantity of water discharge. In addition, forests harbor much of the world's biological diversity. Although scientists know that most of the world's species have not yet been identified, they think that at least half and possibly well over two-thirds of these species are found in forest ecosystems–in particular, in tropical and subtropical forests (Reid and Miller 1989:15).

Forests provided an important springboard for industrial and socioeconomic development for northern hemisphere countries. They were often recklessly used, but former forested lands usually became productive in new ways. For example, wide tracts of forest were converted permanently to agriculture. In some areas, such as parts of the eastern United States, forests that had been clear-cut have regrown. For now, the northern hemisphere and temperature zone industrialized countries–with the exception of Japan–are broadly self-sufficient in wood, though tropical woods must still be imported.

Forests are now playing a similar socioeconomic development role in many developing countries. That role is more critical in these nations because forests supply industrial wood both for domestic consumption and for export to obtain foreign currency. At the same time, traditional goods and services–woodfuels, food, and medicines–continue to support the livelihoods of many rural populations. Millions of people in tropical and subtropical countries still depend entirely on forest ecosystems to meet their every need.

From the range of goods and services provided by forest ecosystems, PAGE focused on five of the most important for human development and well-being: timber production and consumption, woodfuel production and consumption, biodiversity, watershed protection, and carbon storage.

(continues on p. 90)

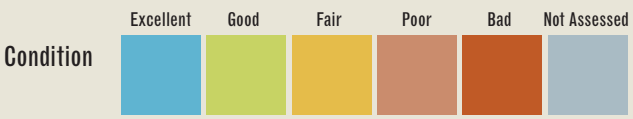
Box 2.17 Taking Stock of Forest Ecosystems

Highlights

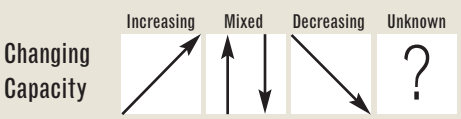
- Forests cover about 25 percent of the world's land surface, excluding Greenland and Antarctica. Global forest cover has been reduced by at least 20 percent since preagricultural times, and possibly by as much as 50 percent.
- Forest area has increased slightly since 1980 in industrial countries, but has declined by almost 10 percent in developing countries. Tropical deforestation probably exceeds 130,000 km^2 per year.
- Less than 40 percent of forests globally are relatively undisturbed by human action. The great majority of forests in the industrial countries, except Canada and Russia, are reported to be in "semi-natural" condition or converted to plantations.
- Many developing countries today rely on timber for export earnings. At the same time, millions of people in tropical countries still depend on forests to meet their every need.
- The greatest threats to forest extent and condition today are conversion to other forms of land use and fragmentation by agriculture, logging, and road construction. Logging and mining roads open up intact forest to pioneer settlement and to increases in hunting, poaching, fires, and exposure of flora and fauna to pest outbreaks and invasive species.

Key

Condition assesses the current output and quality of the ecosystem good or service compared with output and quality of 20–30 years ago.



Changing Capacity assesses the underlying biological ability of the ecosystem to continue to provide the good or service.



Scores are expert judgments about each ecosystem good or service over time, without regard to changes in other ecosystems. Scores estimate the predominant global condition or capacity by balancing the relative strength and reliability of the various indicators. When regional findings diverge, in the absence of global data, weight is given to better-quality data, larger geographic coverage, and longer time series. Pronounced differences in global trends are scored as "mixed" if a net value cannot be determined. Serious inadequacy of current data is scored as "unknown."

Conditions and Changing Capacity

FIBER PRODUCTION

Fiber production has risen nearly 50 percent since 1960 to 1.5 billion cubic meters annually. In most industrial countries, net annual tree growth exceeds harvest rates; in many other regions, however, more trees are removed from production forests than are replaced by natural growth. Fiber scarcities are not expected in the foreseeable future. Plantations currently supply more than 20 percent of industrial wood fiber, and this contribution is expected to increase. Harvesting from natural forests will also continue, leading to younger and more uniform forests.

WATER QUALITY AND QUANTITY

Forest cover helps to maintain clean water supplies by filtering freshwater and reducing soil erosion and sedimentation. Deforestation undermines these processes. Nearly 30 percent of the world's major watersheds have lost more than three-quarters of their original forest cover. Tropical montane forests, which are important to watershed protection, are being lost faster than any other major forest type. Forests are especially vulnerable to air pollution, which acidifies vegetation, soils, and water runoff. Some countries are protecting or replanting trees on degraded hillslopes to safeguard their water supplies.

BIODIVERSITY

Forests, which harbor about two-thirds of the known terrestrial species, have the highest species diversity and endemism of any ecosystem, as well as the highest number of threatened species. Many forest-dwelling large mammals, half the large primates, and nearly 9 percent of all known tree species are at some risk of extinction. Significant pressures on forest species include conversion of forest habitat to other land uses, habitat fragmentation, logging, and competition from invasive species. If current rates of tropical deforestation continue, the number of all forest species could be reduced by 4-8 percent.

CARBON STORAGE

Forest vegetation and soils hold almost 40 percent of all carbon stored in terrestrial ecosystems. Forest regrowth in the northern hemisphere absorbs carbon dioxide from the atmosphere, currently creating a "net sink" whereby absorption rates exceed respiration rates. In the tropics, however, forest clearance and degradation are together a net source of carbon emissions. Expected growth in plantation area will absorb more carbon, but likely continuation of current deforestation rates will mean that the world's forests remain a net source of carbon dioxide emissions and a contributor to global climate change.

WOODFUEL PRODUCTION

?

Woodfuels account for about 15 percent of the primary energy supply in developing countries and provide up to 80 percent of total energy in some countries. Use is concentrated among the poor. Woodfuel collection is responsible for much local deforestation in parts of Asia, Africa, and Latin America, although two-thirds of all woodfuel may come from roadsides, community woodlots, and wood industry residues, rather than forest sources. Woodfuel consumption is not expected to decline in coming decades, despite economic growth, but poor data make it difficult to determine the global supply and demand.

Data Quality

FIBER PRODUCTION

Generally good global data on industrial roundwood production by country are published annually by the Food and Agriculture Organization (FAO) and the International Tropical Timber Organization (ITTO). Production is recorded by value and by volume in cubic meters per year. Various studies forecast future production and consumption rates. Forest inventory data, recording annual rates of tree growth, tree mortality, size and age of stands, and harvest rates, are generally available for industrial countries but are incomplete and must be estimated for many developing countries. Information on plantation extent and productivity varies widely among countries.

WATER QUALITY AND QUANTITY

Global data on current forest cover and historic loss in major watersheds have been compiled by World Resources Institute (WRI). Data on water runoff, soil erosion, and sedimentation in deforested watersheds are available mostly at regional or local levels. Evidence of the importance of forest cover in regulating water quality and quantity is based on experience in forests managed primarily for soil and water protection in the industrial countries and on studies that value forests according to the avoided costs of constructing water filtration plants. Forest degradation by air pollution in Europe is surveyed by the UN Economic Commission for Europe (UN-ECE).

BIODIVERSITY

Global data sets are few, and evidence is often anecdotal. Forests with high conservation value are identified by field observation and expert opinion. More quantitative information on threatened species is available globally for forest trees and regionally for some birds, butterflies, moths, and larger mammals. Good-quality data on restricted-range birds are available, as are data on threatened birds in the neotropics. Identification of global centers of plant diversity is based on field observation and expert opinion.

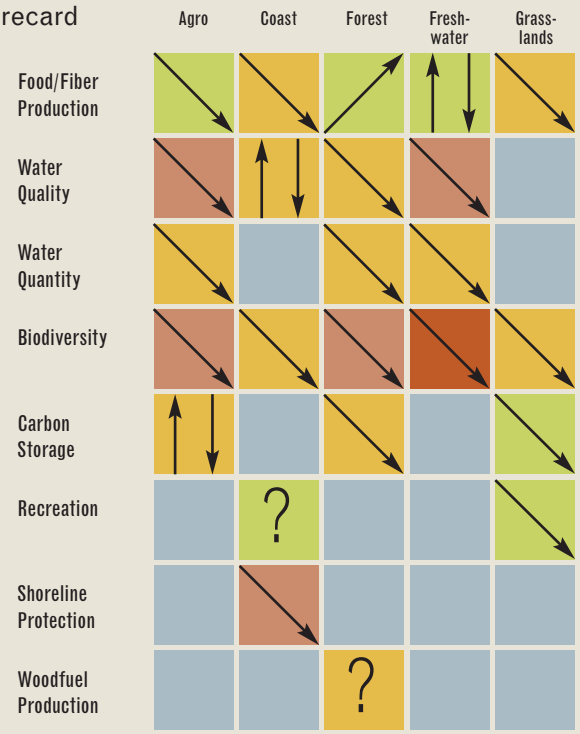
CARBON STORAGE

Methodologies for estimating the size of carbon stores in biomass and soils are developing rapidly. This study relied on the estimates of carbon stored in above- and below-ground live vegetation developed by Olson. This data set was modified by updating carbon storage estimates to accord with the land-cover map from the International Geosphere-Biosphere Programme (IGBP), delineated by global ecosystems. Estimates of soil carbon stores were based on the International Soil Reference and Information Centre—World Inventory of Soil Emission Potentials (ISRIC-WISE) Global Data Set of Derived Soil Properties.

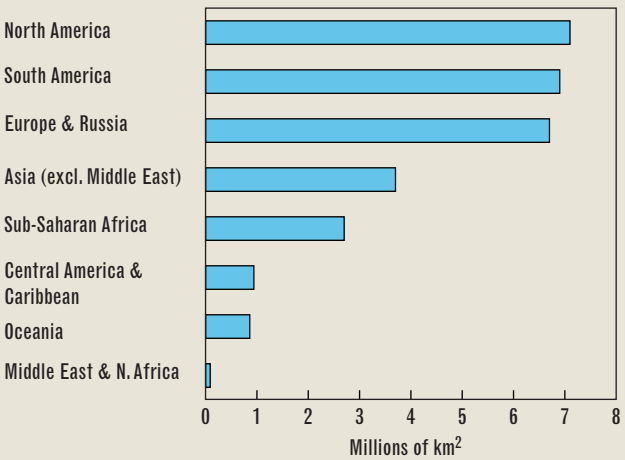
WOODFUEL PRODUCTION

The International Energy Agency (IEA) holds good recent data on wood energy production and consumption in industrial countries, where most wood energy is derived from industrial wood processing residues. Global time series data on woodfuel and charcoal production, available from FAO, are modeled or estimated from household surveys. Data on woodfuel plantations and nonforest sources of production (such as public lands) are patchy. Human dependence on woodfuel in developing countries is largely inferred from information on availability and price of other energy sources.

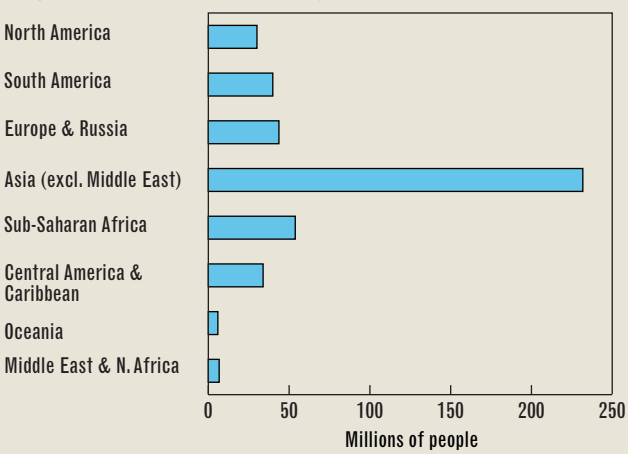
Scorecard



Area of Forest Ecosystems



Population of Forest Ecosystems



Forest Extent and Modification

More than 90 different definitions of "forest" are in use throughout the world, complicating the effort to measure and evaluate global forest ecosystems. PAGE researchers adopted the definition used by IGBP, which defines *forest ecosystems* as "the area dominated by trees forming a closed or partially closed canopy" (Box 2.18 The Changing Extent of Forests). Forest ecosystems include tropical, subtropical, temperate, and boreal forests as well as woodlands.

Using the IGBP definition, and using data from satellite imagery, the PAGE study calculated the total forest area in 1993 as 29 million km^2, approximately 22 percent of the world's land area (excluding Antarctica and Greenland). This estimate differs somewhat from that calculated by FAO, which is compiled from national forest inventories rather than satellite data and reflects a somewhat different definition. (FAO defines forests to be all areas having a minimum crown cover of 10 percent and minimum tree height of 5 m.) The FAO estimate puts global forest area in 1995 at 34.5 million km^2 (FAO 1997a:185), or 27 percent of the world's land area.

The area of transition between forest and other land cover is one of the most dynamic portions of forest ecosystems and makes up a significant percentage of forest ecosystems in many parts of the world. Nearly 4 million km^2 in Africa now qualifies as forest/cropland mosaics; cropland accounts for between 30 percent and 40 percent of the vegetation cover and forests account for some part of the remainder. Because these forest transition zones typically have at least 10 percent crown cover and still contain more than 30 percent agricultural land, PAGE researchers–as well as FAO and other researchers–included them in the analyses of both forest and agricultural ecosystems.

The change from closed forest to a forest-agriculture mosaic inevitably changes the goods and services that the "forest" provides. The transition zone could, in principle, be managed sustainably to provide timber, tree and fodder crops, and shelter for field crops, fuelwood, and habitat for wildlife. But without effective management, land-use change and ecosystem degradation in transition zones can proceed rapidly. Currently, neither national nor global forest inventories offer insight into how fast forest transition zones are expanding or how well they are functioning as ecosystems.

DEFORESTATION AND FOREST LOSS

Human actions have caused the world's forest cover to shrink significantly over the last several millennia, but it is difficult to specify exactly how much. Scientists can't precisely determine what the original extent of forest was prior to human impact. Forests are not static; their size and composition have evolved with changing climate. However, scientists can determine–by using knowledge of the soil, elevation, and climatic conditions required by forests–where forest could potentially exist if it were not for human actions. Comparing this "potential" forest area to today's actual forest cover gives a plausible estimate of historical forest loss.

Using this approach, Matthews (1983:474–487) estimated that as of the early 1980s, humans had reduced global forest cover about 16 percent. Updating this study with more recent deforestation data available from FAO brings the total loss of original forest cover to roughly 20 percent. Historical forest loss could be much higher, however. A 1997 study by WRI, which used a higher resolution map of potential forest than the Matthews study, estimates that original forest cover has been reduced by nearly 50 percent (Bryant et al. 1997:1).

Calculating current deforestation rates is every bit as challenging as estimating past forest loss. FAO estimates that forested area increased by 0.2 million km^2 (2.7 percent) in industrialized countries between 1980 and 1995 (Matthews et al. [PAGE] 2000; FAO 1997a:17), while it decreased by 2 million km^2 (10 percent) in developing countries (FAO 1997a:16–17). FAO also estimates that the rate of forest loss in developing countries decreased by 11 percent between 1980–90 and 1990–95, from 154,600 km^2 to 130,000 km^2 annually (FAO 1997a:18). However, the uncertainty in these estimates is high. Measuring deforestation on a global level is complicated by a scarcity of reliable direct measurements and the expense and difficulty of satellite measurements. As a result, estimates of the current deforestation rate vary widely, from about 50,000 km^2 to 170,000 km^2/year (Tucker and Townshend 2000:1461). Although the FAO estimate of 130,000 km^2/year is widely quoted, more recent studies–notably of Indonesia and Brazil–suggest that it underestimates actual forest loss.[4]

The underlying causes of forest loss have been the focus of many studies and reports over the past several decades. In its 1997 forest assessment, FAO attributes forest loss in Africa principally to the expansion of subsistence agriculture, under pressure from rural population growth (FAO 1997a:20). Forest loss in Latin America was due more to large-scale cattle ranching, clearance for government-planned settlement schemes, and hydroelectric reservoirs. FAO found forests in Asia to be subject about equally to pressure from subsistence agriculture and economic development schemes (FAO 1997a:20).

Historically, woodfuel collection was considered a leading factor in deforestation in some regions of the world; however, better information is undermining that conclusion. FAO does not consider woodfuel collecting to be an important cause of deforestation, although it can add to pressures that degrade forest quality and health. As much as two-thirds of woodfuel is obtained from nonforest sources such as woodlands, roadside verges, and wood industries (FAO 1997c:21).

FOREST FRAGMENTATION

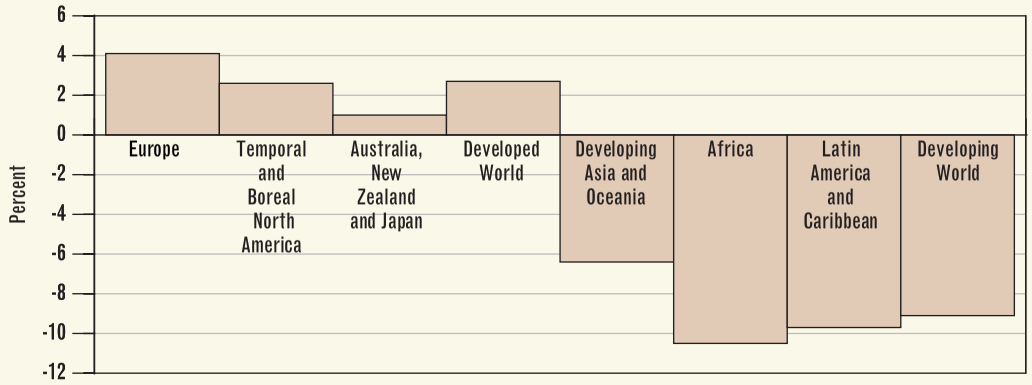
Although change in actual extent clearly has an impact on the various goods and services that forests provide, fragmentation of forests can have just as great an impact. As part of the

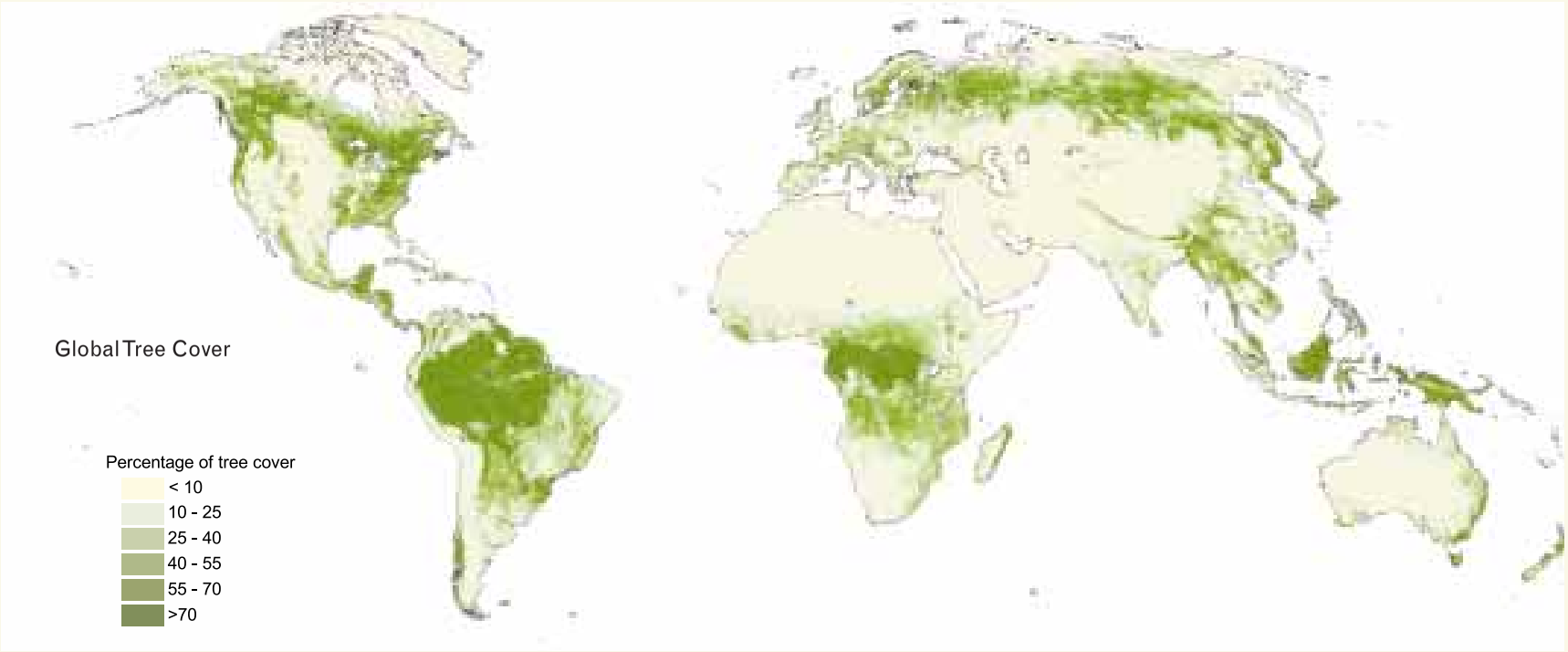
Box 2.18 The Changing Extent of Forests

Since the 16th century, the forests of the northern temperate zone have suffered the most extensive losses as a result of human activity. In recent years, they have begun to recover. However, these gains have been more than offset by rapid decreases in the more extensive and species-rich forests of the developing world.

Many of the world's trees grow within areas that are only partially forested. These lands provide many of the goods associated with forests, especially woodfuel, species habitat, and soil protection. Such areas are particularly vulnerable to clearance, however, since they are often more accessible and less likely to be legally protected than forest areas with higher tree cover.

Change in Forest Area from 1980 to 1995





Sources: Matthews et al. [PAGE] 2000. Map is based on Defries et al. (2000). Figure is based on FAO (1997a).

characterization of the extent and change of forests, PAGE researchers developed an indicator of forest fragmentation based on the world's growing road network. Roads provide development benefits, but they also fragment otherwise continuous stretches of forest.

The impact of fragmentation is twofold. First, fragmentation directly affects species biodiversity by diminishing the amount of natural habitat available, blocking migration routes, providing avenues for invasion by nonnative species, and changing the microclimate along the remaining habitat edge. Second, roads provide access for hunting, timber harvest, land clearing, and other human disturbances that further change the characteristics of the local ecosystem.

Forests are naturally fragmented to some extent by such features as rivers, mountain ranges, natural fires, and storm damage. Road networks, however, provide a relatively unambiguous and globally applicable indicator of human-caused fragmentation, albeit a conservative indicator since human actions fragment forests in other ways as well. To demonstrate the potential use of such a fragmentation indicator, the PAGE study included a pilot analysis of forest fragmentation in Central Africa in which researchers documented the effect of road building in breaking up large forest blocks (Box 2.19 Fragmentation of Forests in Africa). In the absence of roads, large continuous blocks of habitat–more than 10,000 km^2–would naturally make up 83 percent of the forest area in Central Africa. However, in the presence of the existing road network, large forest blocks account for just 49 percent of the forest area (Matthews et al. [PAGE] 2000).

FOREST FIRES

In addition to outright conversion and fragmentation of forests, a third human-caused pressure is the frequency and intensity of fires. Wildfires are a natural and necessary phenomenon in many forest ecosystems, helping to shape landscape structure, improve the availability of soil nutrients, and initiate natural cycles of plant succession. In fact, some plant species can't reproduce without periodic fire.

The number of human-caused fires, however, greatly exceeds naturally occurring fires. Fires are set intentionally for timber harvesting, land conversion, or shifting agriculture, and also in the course of disputes over property and land rights. Tropical forest fires were unusually severe in 1997–98, following less-than-average rainfalls due to El Niño. The number of fires in Brazil increased dramatically between 1995 and 1998, spreading from agricultural areas into moist forest that traditionally had not burned (Elvidge et al. 1999). Brazilian fires increased 50 percent between 1996 and 1997, and another 86 percent between 1997 and 1998 (FAO 1999:3)(Box 2.20 Forest Fires).

Globally, humans initiate as much as 90 percent of total biomass burning (including savannas) (Levine et al. 1999:iv). Human-caused fires are thus already reshaping forest ecosystems and their impact could grow substantially. Recent studies indicate that fires in tropical moist forests create feedback loops that increase the forest's susceptibility to subsequent fires. The first fire serves to open up the canopy, allowing sun and air movement to increase drying of the forest. Previously fire-killed trees increase fuel availability, and invading grasses and weeds add combustible live fuels. Second and third fires are faster-moving, more intense, and of longer duration. Initial fires have been demonstrated to kill no more than 45 percent of trees more than 20 cm in diameter, whereas in recurrent fires, up to 98 percent of trees are liable to be killed (Cochrane et al. 1999:1832–1835). This enhanced fire cycle raises the risk that large areas of tropical forest could be transformed into savanna or scrub.

The social and economic costs of forest fires are also significant. An estimated 20 million people were at risk of respiratory problems from the recent fires in Southeast Asia (Levine et al. 1999:12), with economic damages (excluding health impacts) conservatively estimated at $4.4 billion (Economy and Environment Programme for Southeast Asia 1999, cited in Levine et al. 1999:14).

Despite the advent of satellite imagery and the growing significance of fires to the condition of global forests, no reliable global statistics are available for the total forest area burned annually. Within boreal forests, detailed records for the United States and Canada reveal that the annual area burned has more than doubled in the past 30 years (Kasischke et al. 1999:141, 147). Information about tropical forests is more uncertain. For example, estimates of the total area burned in Indonesia during 1997–98 range from 6,000 km^2 (official Indonesian estimates) to more than 45,000 km^2 (unofficial estimate based on analysis of satellite images) (Levine et al. 1999:8–10).

Assessing Goods and Services

FIBER

Commercial timber production is a major global industry. In 1998, global production of industrial roundwood–which includes all wood not used as fuel–was 1.5 billion m^3 (FAO 2000). In the early 1990s, production and manufacture of industrial wood products contributed about US$400 billion to the global economy, or about 2 percent of global GDP (Solberg et al. 1996:48). North America and Europe dominate production, but the timber industry is of greater economic importance to developing countries such as Cambodia, Solomon Islands, and Myanmar, where wood exports can account for more than 30 percent of international trade (FAO 1997a:36).

The three main sources of industrial roundwood are primary forests, secondary-growth forests, and plantations. Secondary-growth forests have replaced virtually all of the primary or original forests of eastern North America, Europe, and large parts of South America and Asia. Estimates of plantation area vary, partly because of differences

in how plantations are defined. Plantations are generally defined as forests that have considerable human intervention in their establishment and management, but no clear line divides a "plantation" from an intensively managed "secondary forest."

FAO estimates that industrial roundwood plantations account for approximately 3 percent of total forest area, or about 1 million km^2. However, they provide about 22 percent of the world's industrial roundwood supply (Brown 1999:7, 41). Plantation forest area is highly concentrated. Five countries–China, Russia, United States, India, and Japan–account for 65 percent of global plantation forests (Brown 1999:15).

Assessing a forest's capacity to produce timber is difficult in part because the cycle of harvest and regrowth stretches over many decades. One clear indicator that a forest's capacity to produce timber is being degraded would be evidence of harvest rates greater than the rate of tree growth. According to preliminary data (FAO 1998), it appears that many countries are cutting more timber than grows each year.

In most European countries and the United States, the volume of wood felled is less than the volume of yearly growth (FAO 1998:Technical Annex 1). However, in some countries, like the United States, even though net removal is less than net growth, the rate of growth has diminished in recent years (Haynes et al. 1995:43). This imbalance suggests that current timber production may not be sustainable in the long term (Johnson and Ditz 1997:226). Moreover, information about the diameter of trees in the United States indicates a long-term trend toward smaller, younger trees, and a simplified forest structure, with less diversity of sizes and ages of trees. This could, in turn, reduce the diversity of plant and animal species the forest supports.

For most developing nations, there is a lack of reliable data on net annual forest growth and removal rates and the age of trees–information that is needed to accurately assess the long-term condition of forests. Even so, there is considerable evidence that in some regions, harvest rates greatly exceed regrowth. Typically, in such regions, once forest is cleared, the land is eventually converted to other uses. In other regions, overall harvest may be less than annual growth, but not for certain highly valued species such as mahogany, which are harvested at rates far in excess of their growth rate, which will lead to eventual depletion.

The Bottom Line for Fiber Production. Increasing demand for wood fiber has increased production and, in particular, increased the extent of plantations, which now provide 22 percent of the world's industrial wood. This has not reduced pressure on natural forests. Although forests that have been in timber production for decades show no distinct signs that their capacity to maintain that production is in doubt, some indicators give cause for concern. In developing countries, evidence exists of degradation of timber production capacity, and in these regions, after forests are harvested, the land is often converted to other uses.

WOODFUELS

Fuelwood, charcoal, and other wood-derived fuels (collectively known as woodfuels) are the most important form of nonfossil energy. Biomass energy, which includes woodfuels, agricultural residues, and animal wastes, provides nearly 30 percent of the total primary energy supply in developing countries. Rough estimates indicate that more than 2 billion people depend directly on biomass fuels as their primary or sole source of energy. Woodfuels are the dominant form of biomass energy for many countries, although the data are too sparse to know whether this is true for all countries (IEA 1996:II.289–308, III.31–187).

Available data show woodfuels account for more than half of biomass energy consumed in developing countries and, if China is excluded (where agricultural residues are a particularly important fuel), they account for about two-thirds (IEA 1996:II.289–308, III.31–187)(Box 2.21 Global Use of Woodfuels). Woodfuels are also significant sources of energy in some developed countries. Wood energy supplies nearly 17 percent of total energy consumption in Sweden and 3 percent in the United States (FAO 1997b:7, 11). Economic growth in developing countries has reduced the proportion of energy provided by woodfuel, but overall biomass energy consumption has continued to rise.

Will there be enough woodfuel in the future? Already, in some regions, particularly near urban centers, woodfuel availability has decreased significantly in recent decades. In some cases, production has been maintained even in the face of growing demand by tree planting programs and community woodlots. By 2010, an estimated 2.3–2.4 billion m^3 of fuelwood and charcoal will be available (Nilsson 1996), approximately 30 percent more than in 2000. However, woodfuel demand by 2010 is forecast to be 2.4–4.3 billion m^3 (Matthews et al. [PAGE] 2000). Whether a regional or even global woodfuel crisis will develop depends on a variety of factors such as the affordability of alternative fuels. Nevertheless, there is little doubt that growing woodfuel scarcity will increase the economic burden on the poor in some regions.

Perhaps the most striking feature of this information about woodfuels is how limited and imprecise the information actually is. Woodfuel is a critical energy source for a large percentage of the world's population but, despite the efforts of international institutions such as FAO and the International Energy Agency, the information needed to determine whether ecosystems will be able to meet the growing demand is largely unavailable.

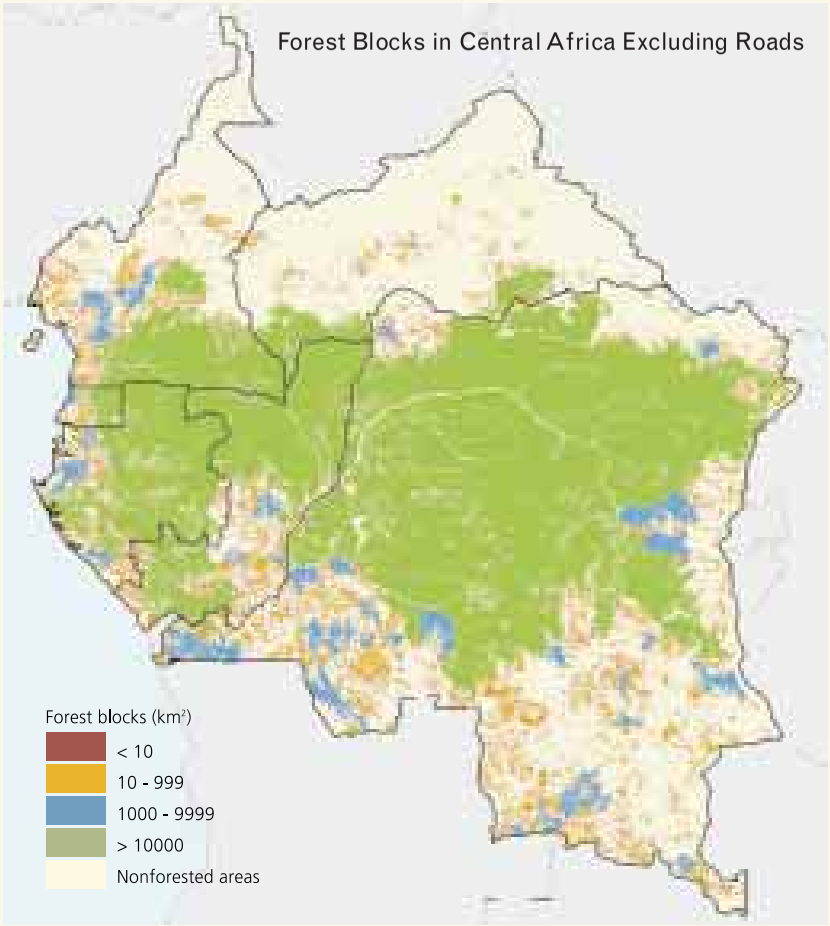
(continues on p. 99)

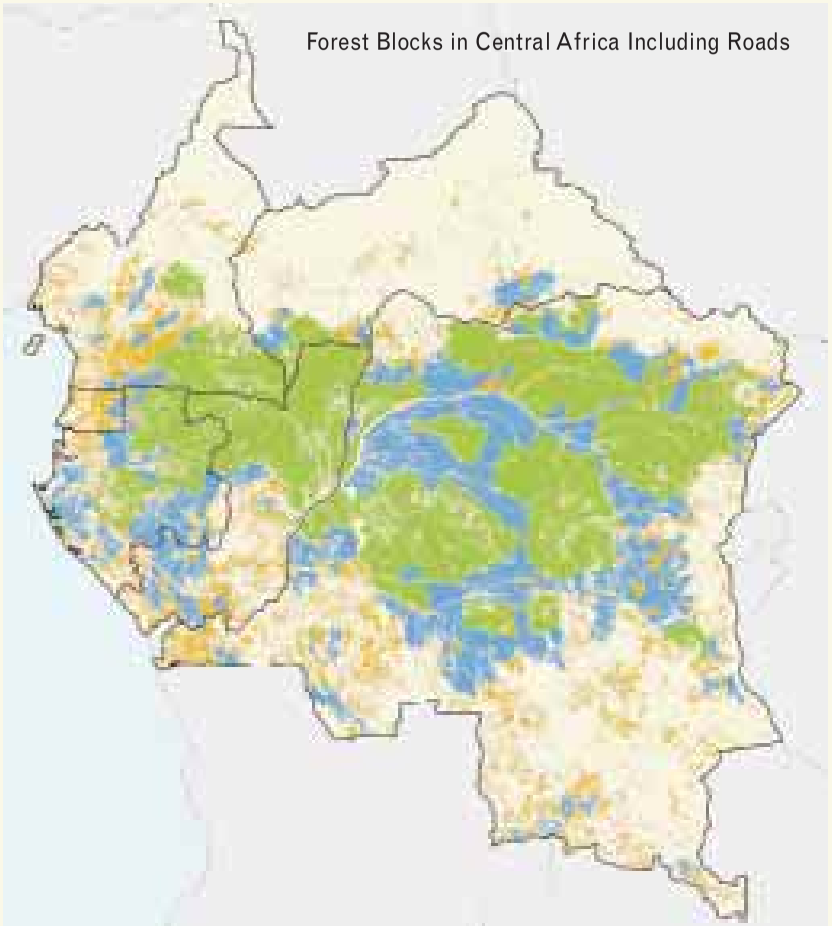
Box 2.19 Fragmentation of Forests in Africa

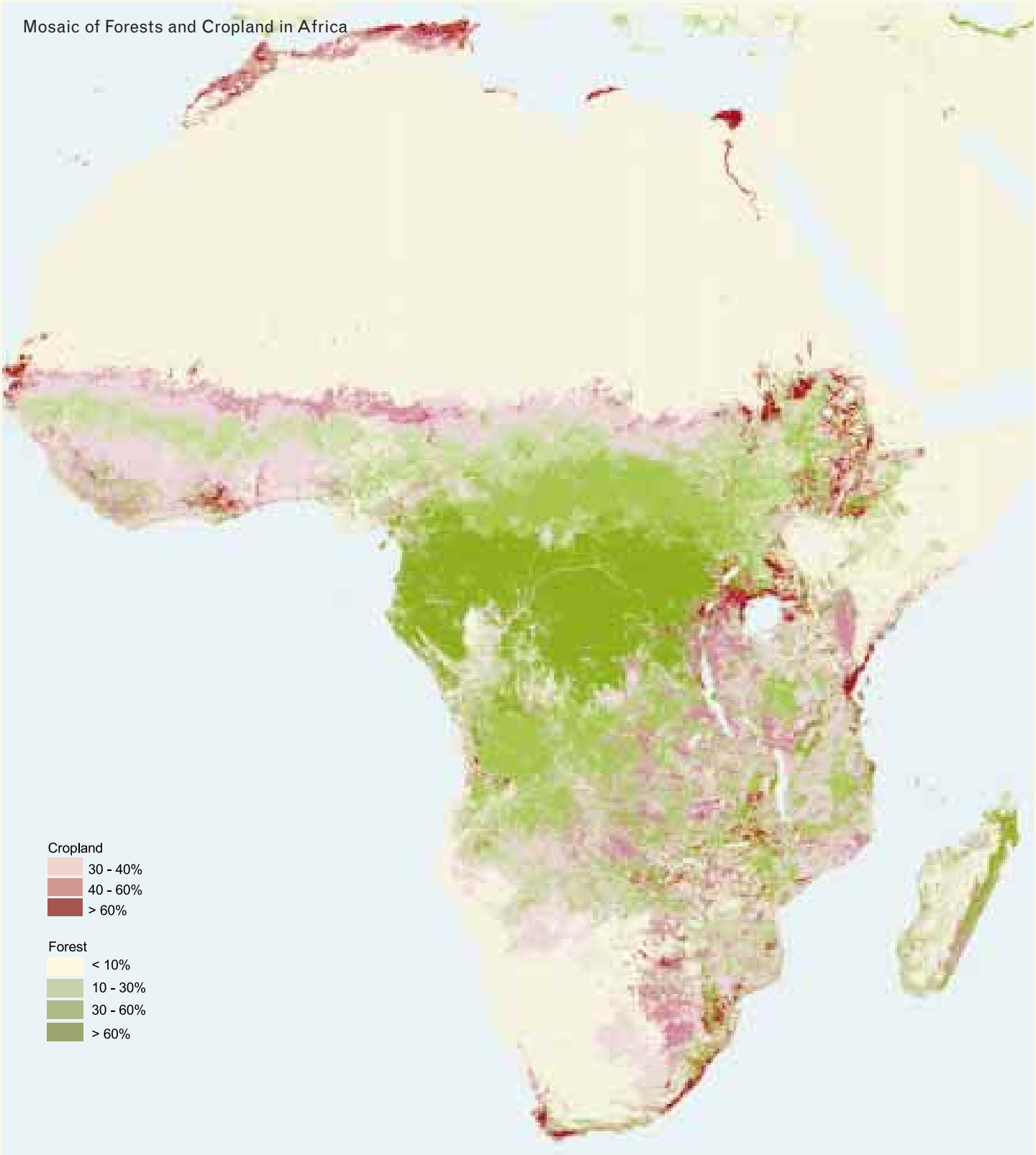
Fragmentation can affect forest ecosystems as profoundly as changes in the total tree cover. In Africa and many other parts of the world, the effect of human encroachment on closed canopy forests has been to create forest "transition zones," in which forested land is interspersed with cropland to form an intricate mosaic, as shown on the facing page.

Road networks provide an unambiguous and easily measured, if conservative, indicator of the extent of human-induced fragmentation. When a road is built through a forest, it breaks up species habitats, sometimes into parcels too small to support viable breeding populations. It also provides avenues for invasion by nonnative species and alters the microclimate along the remaining habitat edge. Roads open up previously inaccessible areas of forest to hunting, timber cutting, and clearing for cultivation.

The maps below show the distribution of various sized blocks of forest in central Africa with and without roads. Without roads, continuous blocks of habitat of more than 10,000 km^2 make up 83 percent of the forested area's total extent. When roads are taken into account, this proportion drops to only 49 percent of the total.





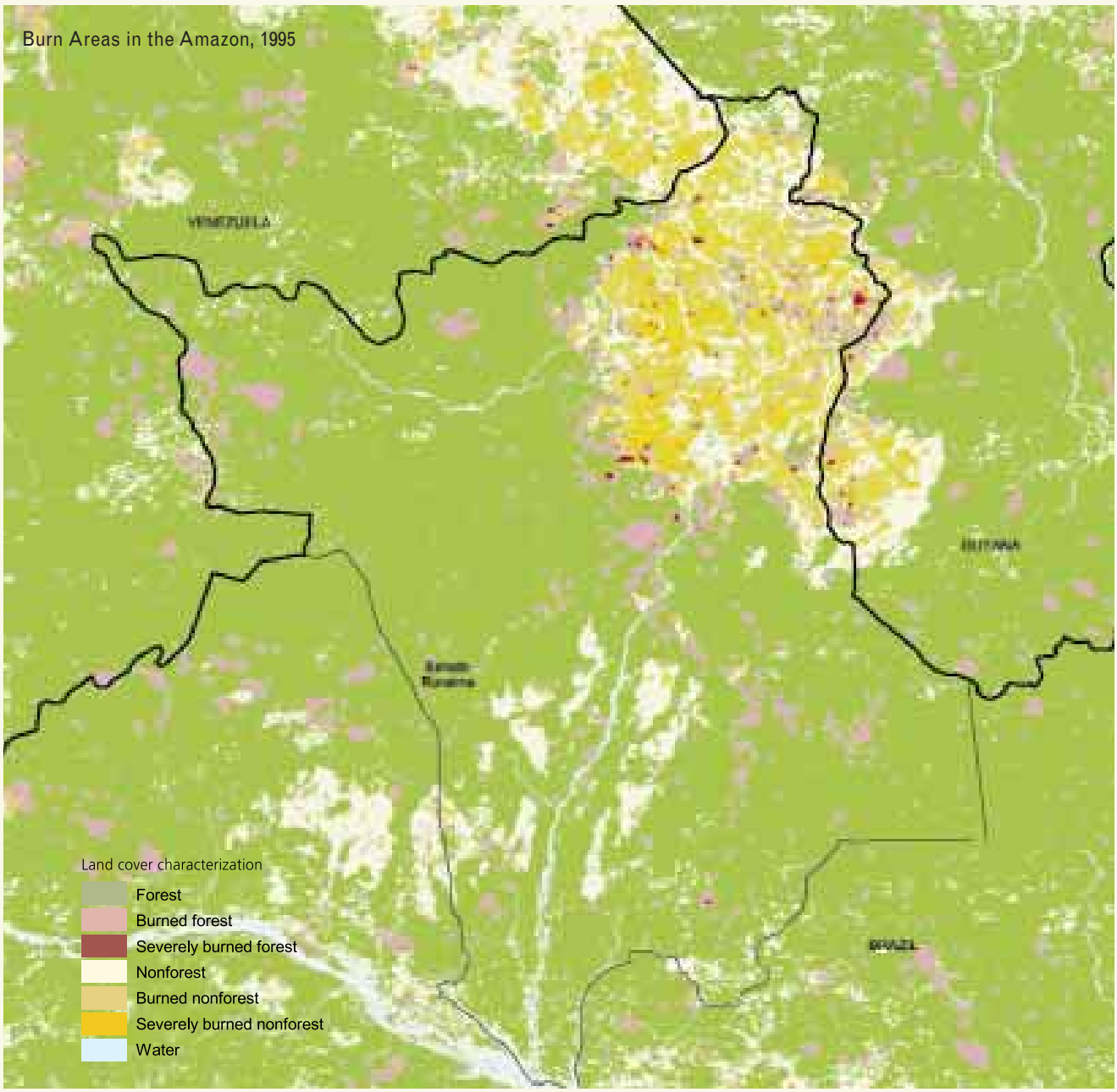


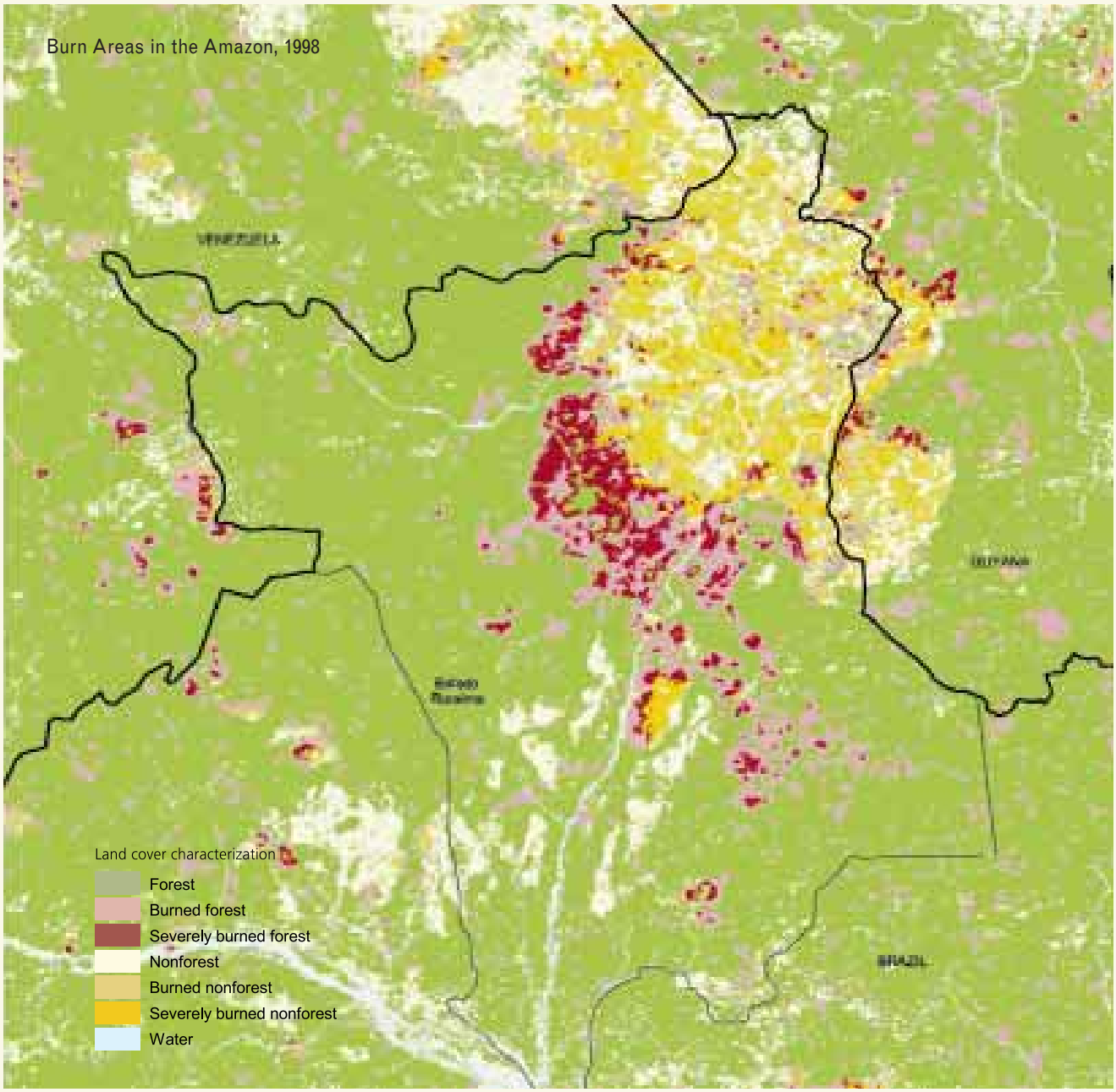
Sources: Matthews et al. [PAGE] 2000. The road fragmentation maps on the previous page are based on CARPE (1998) and Global Land Cover Characteristics Database Version 1.2 (Loveland et al. [2000]). The map above is based on Defries et al. (2000) and Global Land Cover Characteristics Database Version 1.2 (Loveland et al. [2000]).

Box 2.20 Forest Fires

Wildfires are a natural phenomenon in many forest ecosystems. They structure the landscape, improve the availability of soil nutrients, and initiate natural cycles of plant succession. Human-induced fires can have pervasive impact on the condition of forests and their capacity to produce goods and services.

Worldwide, forest fires were especially severe in 1997–98, when millions of hectares of tropical forest in Indonesia, Central America, and the Amazon went up in smoke. Tropical forests, which are normally too wet to sustain extensive fires, were especially susceptible then because of the dry conditions created by El Niño. Evidence suggests, however, that people opportunistically used the dry conditions to set fires to clear land for further development. The burn areas shown for the Amazon in 1998 are adjacent to areas burned to clear land in 1995. This suggests that routine burning of unusually dry fields or pastures may have gotten out of hand. Similar patterns were found in Indonesian forests (Barber 2000).





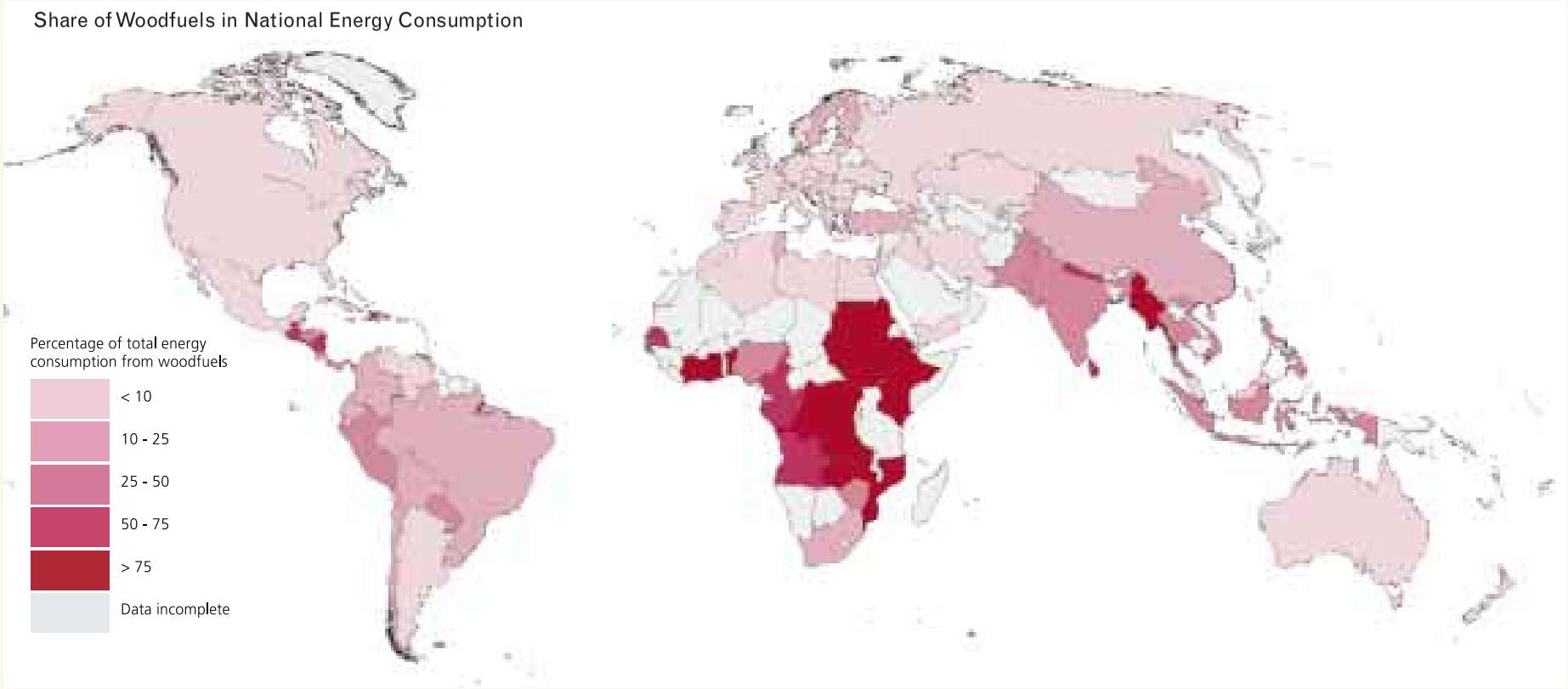
Sources: Matthews et al. [PAGE] 2000. The maps are based on Elvidge et al. (1999) and Global Land Cover Characteristics Database Version 1.2 (Loveland et al. [2000]). Fire data were collected between January and March 1995 and between the same months in 1998. Land-cover data were collected in 1992–93. Nonforested areas include grasslands, croplands, and some seasonal wetlands.

Box 2.21 Global Use of Woodfuels

Woodfuels are the most important source of nonfossil energy. Wood-derived fuels, including fuelwood and charcoal, account for approximately half the biomass energy used in developing countries (IEA 1996), while in some African countries, such as Tanzania, Uganda and Rwanda, woodfuel is the source of 80 percent of total energy consumed.

Although woodfuel collection was assumed to be a major cause of deforestation, recent studies show that up to two-thirds of all woodfuel is collected from nonforest sources such as dispersed woodland and roadside verges (FAO 1997c).

At present, data are insufficient to assess the global sustainability of woodfuel use. It is clear, however, that much of the world's population will continue to rely on wood energy for the foreseeable future and that total demand will increase significantly in coming decades. There is also evidence that in many densely populated areas of the developing world, such as the cities of Côte d'Ivoire, acquiring sufficient wood to meet energy needs is becoming increasingly arduous and costly as populations increase (Garnier 1997).



Sources: Matthews et al. [PAGE] 2000. The map is based on IEA (1996).

The Bottom Line for Woodfuel. Woodfuels are the primary source of energy for approximately 2 billion people and by far the most important of the biomass fuels. But we have inadequate information about actual consumption at the household level or the capacity of ecosystems to continue to provide this good. Woodfuels will remain of prime importance in the developing world for the foreseeable future. It is essential to put wood energy data collection and planning on an equal footing with commercial energy sources like oil, coal, natural gas, and hydroelectricity.

BIODIVERSITY

Forest biodiversity is a good in its own right. Diverse species found only in forest habitats are sources of new pharmaceuticals, genetic resources, and nontimber forest products such as resins, fruits, vines, mushrooms, and livestock fodder. Even more important, all other forest goods and services depend to some extent on the diversity of forest species. The condition of biodiversity is thus a useful indicator of the aggregate condition of the forest ecosystem.

Forests are particularly important ecosystems for biodiversity conservation. Two-thirds of 136 ecologically distinct terrestrial regions identified as outstanding examples of biodiversity are located in forested regions, according to WWF (Olson and Dinerstein 1998:509). Similarly, BirdLife International identified 218 areas containing two or more species of birds with restricted ranges. BLI reasoned that these "narrowly endemic" species were likely to be most susceptible to extinction. Eighty-three percent of these 218 areas occur in forests, mostly tropical lowland forests (32 percent) and montane moist forest (24 percent) (Stattersfield et al. 1998:31). Finally, of 234 centers of plant diversity worldwide identified by IUCN and WWF, more than 70 percent are found in forests (Davis et al. 1994, 1995:12–36).

The condition of forest biodiversity can be most directly measured by changes in the number of species found in the forest, including loss or extinction of native species or introductions of nonnative species. Any change in the number or relative abundance of different species represents ecosystem degradation from the standpoint of biodiversity. Because most species have not yet even been identified, it is possible to monitor threats to only the best-known species groups: in practice, this means birds and trees. Of an estimated 100,000 species of trees, WCMC reports that more than 8,700 (Oldfield et al. 1998) are now threatened globally (Box 2.22 Endangered Trees).

Similar global data for forest-dwelling birds have not been compiled, but BLI has mapped the locations of 290 threatened birds in the Neotropics (excluding the Caribbean), allowing comparison among different ecosystems to determine where threats are greatest. Of 596 key areas harboring threatened species, more than 70 percent were in forests (Wege and Long 1995:15–16).

Another direct measure of biodiversity condition is the extent to which invasive species have colonized an ecosystem. Invasions by nonnative species are now ranked by many ecologists as second only to habitat conversion as a threat to global biodiversity. Comprehensive global data on invasives is not yet available, but information compiled by WWF shows how invasive plants have changed the condition of biodiversity in North American forests. In northeastern coastal forests of the United States, up to 32 percent of total vascular plant species are nonnative, although it is not known how many of these species are harmful (Ricketts et al. 1997:82).

Although these direct measures of change in the number of species in forests are the best way to assess the condition of forest biodiversity, data are unavailable for much of the world. Consequently, most of what is known about the condition of forest species is only inferred from various measures of the pressures on forest biodiversity. Three such pressures–habitat fragmentation, logging, and loss of habitat area–are known to change the numbers and types of species found in forest regions. Areas with high levels of fragmentation or logging, or regions that have experienced significant loss of forest habitat, will not contain as many of the native species previously found in the region.

The relationship between habitat area and species diversity is well enough established that it is possible to estimate how many native species might ultimately be lost from a particular habitat as its area is reduced. The Global Biodiversity Assessment conducted in 1995 under the auspices of UNEP found that if recent rates of tropical forest loss continue for the next 25 years, the number of species in forests would be reduced by approximately 4–8 percent (Heywood 1995:235).

The Bottom Line for Biodiversity. Forests have the highest species diversity and endemism of any ecosystem. Pressure on this diversity is immense, as judged from forest loss and fragmentation, but direct information about condition is more limited. What evidence exists suggests that the number of threatened forest species is significant and growing, and species introductions are very high in certain regions. Not only is forest area shrinking, but the capacity of remaining forests to maintain biodiversity appears to be significantly diminished.

CARBON STORAGE

Forests play a central role in the global carbon cycle. Trees capture carbon from the atmosphere as they grow and store it in their tissues. Because of their great biomass, global forests comprise one of the largest terrestrial reservoirs or "sinks" of carbon. Forests store 39 percent (471–929 GtC) of the 1,213–2,433 GtC that PAGE researchers calculated are stored in all terrestrial ecosystems. By way of comparison, grass-

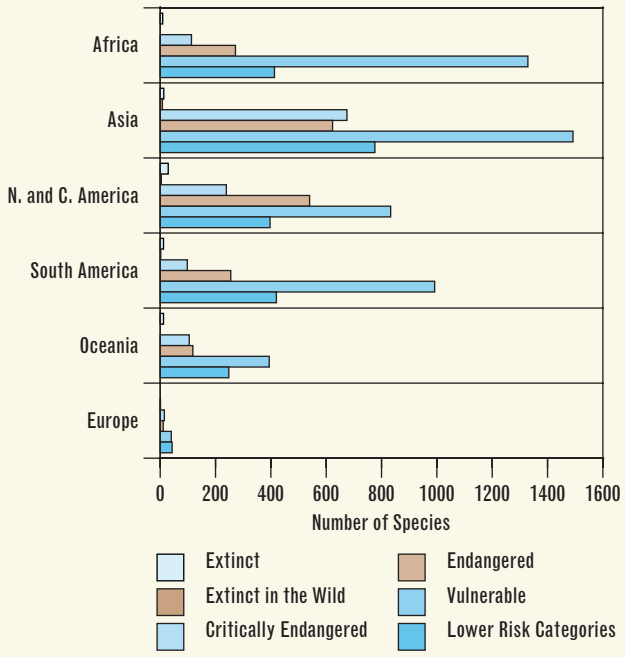
Box 2.22 Endangered Trees

Survival of the world's estimated 100,000 tree species is threatened by conversion of forest land to other uses, timber harvesting, fire, pest attack, and ecosystem simplification resulting from forest management. WCMC has compiled a list of threatened species, assessed according to the 1994 IUCN categories of threat. Altogether, more than 8,700 tree species, almost 9 percent of the world total, are at risk.

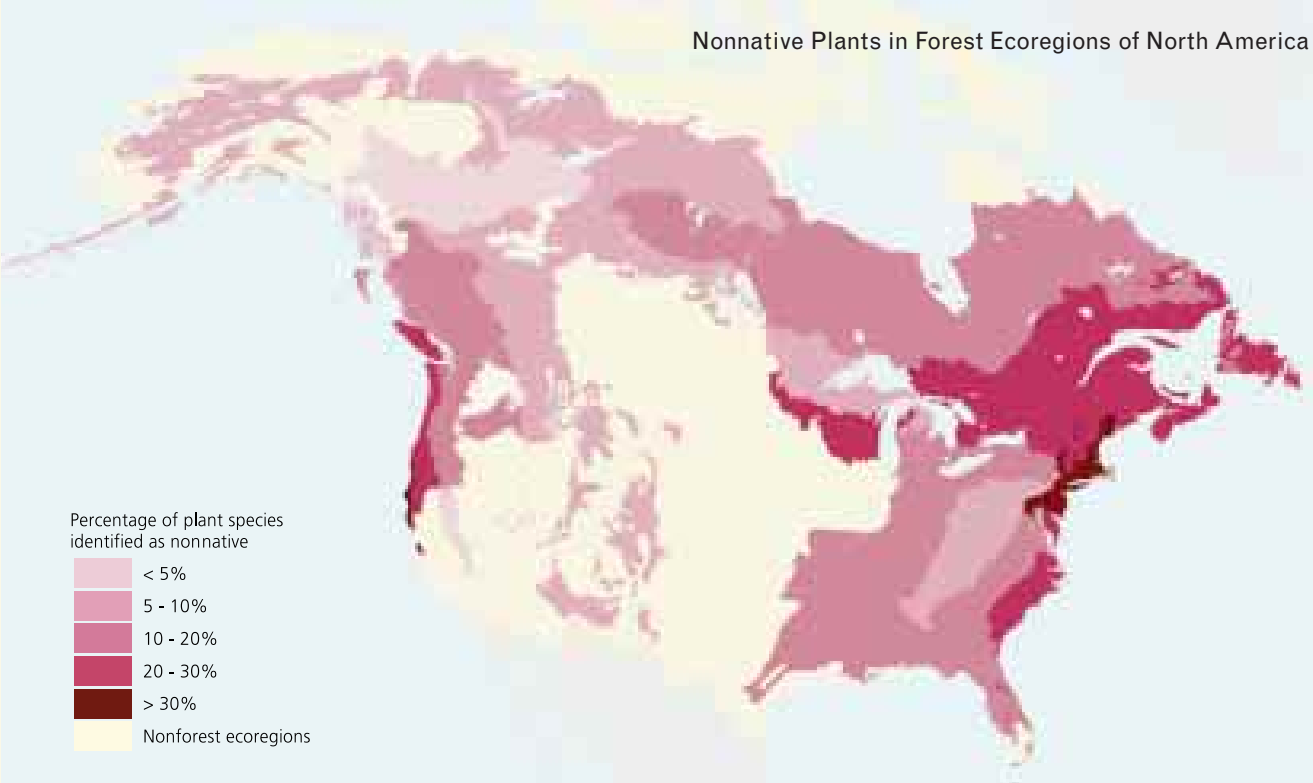
A major threat is posed by the deliberate or accidental introduction by humans of nonnative plants and animals to forest habitats. These can threaten the survival of native species by attacking them, competing with them for food and space, or altering local ecosystems to the point that they can no longer support indigenous tree populations. The number of nonnative species are, thus, an indicator of the degree of potential "assault" on native flora.

In North America, the highest concentrations of nonnative species are found around ports, along major transportation routes, and in fertile agricultural regions that have proved favorable to both introduced crops and their pests. Densely forested taiga regions away from major human settlements appear to be little affected, and the conifer forests of the Southeast have proved relatively resistant to invasive species.

Risk Categories for the World's Trees



Nonnative Plants in Forest Ecoregions of North America



Sources: Matthews et al. [PAGE] 2000. The map is from Ricketts et al. (1997). The figure is based on Oldfield et al. (1998).

lands store about 33 percent of terrestrial carbon, yet cover nearly twice as much area as forested regions.

Land-use change is thought to release an average of 1.6 GtC to the atmosphere each year, or roughly 20 percent of all carbon emissions caused by human action (IPCC 2000:5). By far the most significant component of global land-use change is deforestation in the tropics (Houghton 1999:305, 310). Clearing forests and burning the debris releases large amounts of carbon stored in the vegetation back into the atmosphere. On the other hand, restoring degraded forests or changing their management can increase their carbon storing ability and thus increase the total carbon stored in world forests.

Loss of carbon storage in forests does not always take the form of large-scale clearance or outright deforestation. Logging and clearing small areas for agriculture can also degrade forests and significantly reduce their carbon-storing capacity. One recent study in tropical Asia reported that deforestation accounted for two-thirds of carbon loss in Asian forests, whereas one-third was due to degradation from logging and shifting cultivation (Houghton and Hackler 1999:486). Another study, in Africa, found that outright loss of forest accounted for 43 percent of carbon loss, while degradation of the forest was responsible for 57 percent (Gaston et al. 1998:110).

The Bottom Line for Carbon Storage. Forests store more carbon than any other terrestrial ecosystem—nearly 40 percent of total carbon stored. Deforestation and forest degradation are responsible for approximately 20 percent of annual carbon emissions. The condition of forest ecosystems from the standpoint of carbon storage is clearly declining, but with appropriate economic incentives, this trend could potentially be reversed. However, there are trade-offs to be borne in mind: more carbon is sequestered by young, fast-growing trees than by mature trees. Simply managing forests to store maximum carbon might encourage replacement of many existing old-growth forests with plantations, which would clearly jeopardize biodiversity, tourism, and other services that natural forests provide.

WATER QUALITY AND QUANTITY

Forests provide several valuable services in relation to watershed protection. They physically stabilize the upper reaches of watersheds. Tree roots "pump" water out of the soil to be used by the plant, thereby reducing soil moisture and the likelihood of mud slides; root structures increase the shear strength of soil and help prevent landslides. Forests also tend to moderate the rate of runoff from precipitation, reducing flows during flooding and increasing flows during drier times.

Forest cover also helps to maintain drinking water supplies. Within the United States, more than 60 million people in 3,400 communities rely on National Forest lands for their drinking water, a service estimated to be worth $3.7 billion per year (Dombeck 1999). Finally, forest cover affects the total amount of water available in a watershed. In many regions, forest loss will increase net water discharge because less water is transpired to the atmosphere. In other regions, however, forest loss can decrease net discharge. In cloud forests, for example, forests play a role in directly condensing or "stripping" water from moisture-laden air and making it available for discharge. In other regions, precipitation is dependent in part on the transpiration of water-laden air from the local forest. For example, climate researchers have estimated that temperatures are about 1°C higher and precipitation is 30 percent lower in large deforested patches in the Amazon (Couzin 1999:317).

Overall, forest loss has certainly impaired the world's watersheds to a significant degree. A 1998 analysis by WRI found that nearly 30 percent of the world's major watersheds have lost more than three-fourths of their original forest cover, and 10 percent have lost more than 95 percent of their original forest cover (Revenga et al. 1998:I-13) (Box 2.23 The Deforestation of Watersheds).

Perhaps a more revealing measure of the condition of forests for watershed protection today is the status of montane forests. These forests play an especially important role in the hydrological processes of watersheds by controlling soil erosion in steeply sloping mountains and sometimes "capturing" water in cloud forests.

In temperate regions, the extent of montane forest has increased in recent years, except in the mature old-growth coniferous forests of the Pacific Northwest of North America, Chile, Tasmania, and southern New Zealand. Highly prized for producing lumber, these forests may have been reduced to less than half their original extent by logging (Denniston 1995:32). In the tropics, montane forests are under even greater pressure. According to FAO, tropical montane forests were disappearing at a rate of 1.1 percent/year in the 1980s, which exceeded the rate of loss for all other tropical forest types (FAO 1993:28).

The Bottom Line for Water Quality and Quantity. Forests retain water in soil, regulate flow, influence precipitation, and filter drinking water. The water purification service alone has high economic value in certain regions. Forest loss in general has eroded the capacity of the world's forests to protect watersheds and provide water-related services, and this decline will likely continue as pressures on forests mount. Nearly 30 percent of the world's major watersheds have lost more than three-quarters of their original forest. Montane forests, which are particularly important in protecting watersheds, have suffered extensively. In spite of the importance of forests for vital water services, these services are rarely factored into land-management decisions.

Box 2.23 The Deforestation of Watersheds

Deforestation is a useful indicator of watershed degradation, because forests are often crucial for maintaining water quality and moderating water flow. The loss of original forest cover is estimated from the extent of forests that are believed to have existed 8,000 years ago assuming current climate conditions. Almost a third of all watersheds have lost more than 75 percent of their original forest cover, and seventeen have lost more than 90 percent. Most of these basins are relatively small. Large basins, such as the Congo and the Amazon, still have extensive original forest cover and have lost a relatively small percentage of their original forest. Nonetheless, the total area of original forest lost is large: nine large basins have lost more than 500,000 km^2 (Revenga et al. 1998:I-13).

Watersheds Losing the Greatest Share of Original Forest Cover

Region and Watershed	Percentage of Original Forest Lost
Africa	
Lake Chad	100
Limpopo	99
Mangoky	97
Mania	98
Niger	96
Nile	91
Orange	100
Senegal	100
Volta	97
Asia and Oceania	
Amu Darya	99
Indus	90
Europe	
Guadalquivir	96
Seine	93
Tigris & Euphrates	100
South America	
Rio Colorado	100
Lake Titicaca	100
Uruguay	92

Watersheds Losing the Greatest Area of Original Forest Cover

Region and Watershed	Area of Original Forest Lost (km^2)
Africa	
Congo	>1,000,000
Asia and Oceania	
Ganges	500,000–1,000,000
Mekong	500,000–1,000,000
Ob	500,000–1,000,000
Yangtze	>1,000,000
Europe	
Volga	500,000–1,000,000
North America	
Mississippi	500,000–1,000,000
South America	
Amazon	500,000–1,000,000
Paraná	500,000–1,000,000

Source: Revenga (personal communication, 2000) updating Revenga et al. (1998).