Chapter 21

Forest and Woodland Systems

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*This appears in Appendix A at the end of this volume.

Main Messages

Forest ecosystems are extremely important refuges for terrestrial biodiversity, a central component of Earth's biogeochemical systems, and a source of ecosystem services essential for human well-being. The area and condition of the world's forests has, however, declined throughout recent human history. In the last three centuries, global forest area has been reduced by approximately 40%, with three quarters of this loss occurring during the last two centuries. Forests have completely disappeared in 25 countries, and another 29 countries have lost more than 90% of their forest cover. Although forest cover and biomass in Europe and North America are currently increasing following radical declines in the past, deforestation of natural forests in the tropics continues at an annual rate of over 10 million hectares per year—an area larger than Greece, Nicaragua, or Nepal and more than four times the size of Belgium. Moreover, degradation and fragmentation of many remaining forests are further impairing ecosystem functioning.

Information about the world's forest is limited and unevenly distributed. The *Global Forest Resources Assessment 2000* (FRA-2000) done by the Food and Agriculture Organization of the United Nations reports that only 22 out of 137 developing countries possess a series of time-series inventories, 28 countries have no inventory, and 33 have only partial inventories. Further, 34 countries only have national forest inventories from before 1990, while only 43 have inventories completed after 1990. More than half the inventories used to compile FRA-2000 were either more than 10 years old or incomplete. Forest information is also inadequate—and sometimes statistically unreliable—for many industrial countries. Despite the proliferation of new remote sensing technologies, the reliability of remote sensing products remains uncertain.

Forests, particularly those in the tropics, provide habitat for half or more of the world's known terrestrial plant and animal species. This biodiversity is essential for the continued health and functioning of forest ecosystems, and it underlies the many ecosystem services that forests provide.

Forests and woodlands play a significant role in the global carbon cycle and, consequently, in accelerating or decelerating global climate change. Forests contain about 50% of the world's terrestrial organic carbon stocks, and forest biomass constitutes about 80% of terrestrial biomass. Forests contribute over two thirds of global terrestrial net primary production. Slowing forest loss and restoring forest cover in deforested areas could thus help mitigate climate change.

More than three quarters of the world's accessible freshwater comes from forested catchments. Water quality declines with decreases in forest condition and cover, and natural hazards such as floods, landslides, and soil erosion have larger impacts.

The provisioning services obtained from forests have substantial economic value. Forests annually provide over 3.3 billion cubic meters of wood (including 1.8 billion cubic meters of fuelwood and charcoal), as well as numerous non-wood forest products that play a significant role in the economic life of hundreds of millions of people. The combined economic value of "non-market" (social and ecological) forest services may exceed the recorded market value of timber, but these values are rarely taken into account in forest management decisions.

The rural poor are particularly dependent on forest resources. As many as 300 million people, most of them very poor, depend substantially on forest ecosystems for their subsistence and survival. The 60 million indigenous people who live in forest areas are especially dependent on forest resources and the health of forest ecosystems. Although use of forest resources on its own is often insufficient to promote poverty alleviation, forest loss and degradation has significant negative consequences on human well-being.

Forests play important cultural, spiritual, and recreational roles in many societies. For many indigenous and otherwise traditional societies, forests play an important role in cultural and spiritual traditions and, in some cases, are integral to the very definition and survival of distinct cultures and peoples. Forests also continue to play an important role in providing recreation and spiritual solace in more modernized, secular societies, and forests and trees are symbolically and spiritually important in most of the world's major religious traditions.

Forest loss and degradation are driven by a combination of economic, political, and institutional factors. The main direct drivers of tropical deforestation are agricultural expansion, high levels of wood extraction, and the extension of roads and other infrastructure into forested areas. Indirect drivers include increasing economic activity and associated market failures, a wide range of policy and institutional weaknesses and failures, the impacts of technological change, low public awareness of forest values, and human demographic factors such as population growth, density, and migration. While temperate and boreal forest cover has stabilized and even increased, the quality of these forests is still threatened by air pollution, fire, pest and disease outbreaks, continued fragmentation, and inadequate management. Climate change threatens forests in all biomes.

Many forests are used almost to their full potential to provide fiber and fuel. By 2020, demand for wood and woodfuel is expected to grow considerably. This growth in demand is likely to stimulate the establishment of more industrial plantations, more-careful management of natural forests, and technological improvements in the efficiency of wood use. However, the establishment of plantations often results in trade-offs with services other than fiber production and with biodiversity.

Many developing countries have not effectively used forest resources in support of development efforts. Widespread corruption in the forestry sector has resulted in valuable forest resources frequently being seized and controlled by political and economic elites. The poor have often seen access to forest resources diminish and have not widely shared in the benefits of forest resource exploitation.

The paradigm of sustainable forest management has been widely embraced at national and international policy levels, but it has not yet been implemented to the point where it is appreciably mitigating the negative trends affecting the world's forests. SFM provides an increasingly sophisticated set of policies and tools for setting forest management on a more sustainable trajectory. Implementing SFM, however, requires overcoming many of the same economic, political, and institutional hurdles that drive deforestation and forest degradation. In addition, forest management would benefit from anticipating and incorporating resilience to the present and likely future impacts of climate change on forest ecosystems. Past policies aspired to control change in forest ecosystems assumed to be stable. The new imperative is to develop policies to manage the capacity of forest to cope with, adapt to, and shape changes. Responding to this imperative requires new information and new knowledge, including advanced science and technology, more effective national and global systems for forest inventory and monitoring, involvement of people in decision-making about forest management and use, and strengthened dialogue and cooperation with decision-makers in other sectors.

21.1 Introduction

Forest ecosystems, which for the purposes of this chapter include woodlands with an interrupted tree canopy, serve important ecological functions and provide wood and numerous other products that contribute significantly to human well-being at local, national, and global levels. The diverse ecosystem services provided by forests include the conservation of soil and water resources, positive influences on local climate, the mitigation of global climate change, the conservation of biological diversity, improvement of urban and peri-urban living conditions, the protection of natural and cultural heritage, subsistence resources for many rural and indigenous communities, the generation of employment, and recreational opportunities. Research indicates that forests supply about 5,000 different commercial products (Chiras 1998), and the forestry sector contributes about 2% of global GDP (FAO 1997). The centrality of forests for humanity has been acknowledged internationally in recent environmental agreements and processes including the United Nations Framework Convention on Climate Change, the Convention on Biological Diversity, the United Nations Convention to Combat Desertification, and the United Nations Forum on Forests.

While it is clear that the value of forest ecosystem services is very high, there are many gaps in scientific understanding and few practical solutions to reconciling the conflicts that arise from the competing values that different user groups ascribe to different forest services. Interests of landowners, local communities, governments, and the private sector vary and frequently conflict in both spatial and temporal terms. The time horizon for using individual forest services is substantially different, for example, for forest-dependent indigenous communities and large logging companies.

About 8,000 years ago, forest covered an estimated 6.2 billion hectares of the planet—about 47% of Earth's land surface (Billington et al. 1996). Peoples of the preagricultural era likely had significant impacts on these forest ecosystems. Some aboriginal tribes are thought to have caused numerous extinctions (such as of North American and Australian megafauna) (Flannery 1994, 2001), and forest has been actively cleared and manipulated in composition through fire and other means for thousands of years (Williams 2003).

From today's perspective, however, preagricultural impacts on overall forest cover appear to have been slight. Since that time, the planet has lost about 40% of its original forest (*high certainty*), and the remaining forests have suffered varying degrees of fragmentation and degradation (Bryant et al. 1997; Matthews et al. 2000; Ball 2001; Wade et al. 2003). Most of this loss has occurred during the industrial age, particularly during the last two centuries, and in some cases much more recently. Some analyses have yielded substantially smaller estimates. Richards (1990), for example, estimates global loss of forests to have been only about 20%.

Much of the progress of human civilization has been made possible by the conversion of some forest areas to other uses, particularly for agricultural expansion. However, this process has resulted in many trade-offs with forest ecosystem services, many of which have not been recognized.

Extensive biodiversity loss—including losses of genetic, species, and habitat diversity—has been one result of the shrinking of the world's forests (Myers 1996; McNeely et al. 1995; Reid and Miller 1989). There is also evidence that forest genetic resources as a whole have declined in quality, especially in areas where high-quality timber has been selectively extracted (Rodgers 1997; Kemp and Palmberg-Lerche 1994). Forest loss has also had a negative impact on the provision of ecosystem services, such as regulation of hydrological cycles. The negative impacts of deforestation appear most directly at the local level, where communities lose access to timber, fuelwood, and bushmeat or suffer increased flooding and landslides. Impacts have also been felt on a much larger scale as well. The widespread salinization of land and rivers in Australia, for example, is the result of extensive woodland clearing and the subsequent introduction of European agriculture (McFarlane et al. 1992; MDBC 1999).

Public awareness of the importance of forests and public concern over forest loss has grown substantially over the past several decades. Numerous international bodies such as the World Commission on Environment and Development (WCED 1987) and the World Commission on Forests and Sustainable Development (WCFSD 1999) have voiced concern about the deepening forest crisis, and the theory and practice of making the transition to "sustainable forest management" is a topic of intensive national and international debate. (See Box 21.1.)

The forest issue was a contentious topic at the 1992 U.N. Conference on Environment and Development, which sought—and ultimately failed—to reach agreement on an international convention on forests. Instead, UNCED adopted a nonbinding set of "Forest Principles," which gave life to a series of U.N. forest initiatives: the Intergovernmental Panel on Forests (1995–97), the Intergovernmental Forum on Forests (1997–2000), the United Nations Forum on Forests (2000–05), and the Collaborative Partnership on Forests (2000). These bodies have provided an important international "soft law" forum to debate global forest policy and have catalyzed a considerable amount of technical work on forest management and policy. It is nevertheless unclear to what extent this international forest policy architecture influences the government and private-sector decisions that actually affect forests on the ground (Chaytor 2001; Bass 2003). Current international and national processes addressing forest management are discussed in detail in MA *Policy Responses,* Chapter 8.

Reliable and comprehensive data and information are essential for determining forest conditions and trends and for development of national and international forest policies. As a whole, information on the world's forests has improved over the past few decades. This is partly a result of the emergence of new technologies such as remote sensing, but it is also due to improving data collection in some countries and to the efforts of scientific researchers and international institutions.

FAO holds the mandate within the U.N. system to compile, analyze, and supply global forest information, and the organization has steadily improved its capacities in this regard, resulting most recently in the *Global Forest Resources Assessment 2000,* discussed at length in this chapter. The UNEP World Conservation Monitoring Centre is another institution that has developed extensive information sources on the conservation aspects of forests. National reporting requirements under environmental conventions such as UNFCCC, CBD, and UNCCD are also a relatively new source of forest information. Many important contributions have been made by the scientific community as well (see, e.g., Wade et al. 2003). Finally, a number of international nongovernmental organizations such as IUCN–World Conservation Union, the World Wide Fund for Nature, and the World Resources Institute have developed their capacities to compile, analyze, and disseminate high-quality forest information.

Despite this progress, available information on the world's forests still contains many gaps and shortcomings. National data for some countries are not reliable, and the overall state of knowledge about the condition and trends of forests in many regions is incomplete. In addition, improvements in forest information have not been accompanied by effective sustainable forest management. Instead, increasing information capacities have provided an ever-more detailed picture of forest decline and its impacts on human well-being.

BOX 21.1

Defining and Measuring "Sustainable Forest Management"

It is well established that "sustainability" means satisfying present needs without compromising future options, but it is not obvious what this means in practical terms for forest management. The concept of "sustained yield" forest management for timber—based on the concept of equilibrium between growth and timber harvest that can be sustained in perpetuity (Thang 2003)—has evolved in line with the broader view of sustainable development articulated by the World Commission on Environment and Development (WCED 1987) and endorsed by the 1992 UNCED Forest Principles, subsequent international processes, as well as many national forest policies. The MA thus differentiates "sustained yield management"—the management and yield of an individual resource or ecosystem service—and "sustainable management," which refers to the goal of "ensuring that a wide range of services from a particular ecosystem is sustained" (MA 2003).

Although sustainable forest management is now widely accepted as the overriding objective for forest policy and practice, it is not easy to define. The problem is that "what is defined as sustainable forestry will vary greatly over space and time as society's needs and perceptions evolve." The Center for International Forestry Research therefore adopted a broad definition in which sustainable forest management means "maintaining or enhancing the contribution of forests to human well-being, both of present and future generations, without compromising their ecosystem integrity, i.e., their resilience, function and biological diversity" (Sayer et al. 1997). Further specification can only be accomplished through the elaboration of SFM criteria and both quantitative and qualitative indicators to measure progress in meeting those criteria. Accordingly, the Intergovernmental Panel/Forum on Forests process identified the development of SFM criteria and indicators as a high priority for international and national action, and nine regional processes involving 149 countries have been launched since 1992 to develop and implement SFM C&I (ECOSOC 2004).

Each of these processes is developing its own distinctive set of C&I to measure progress toward SFM in particular regions and forest biomes (Anonymous 1994, 1995; ITTO 1998; CCFM 2003). CIFOR, meanwhile, has developed a "C&I Toolbox" for the forest management unit level, which includes a generic C&I template (CIFOR C&I Team 1999). The template elaborates C&I within the framework of six SFM objectives:

- policy, planning, and institutional framework are conductive to sustainable forest management;
- ecosystem integrity is maintained;
- forest management maintains or enhances fair intergenerational access to resources and economic benefits;
- concerned stakeholders have acknowledged rights and means to manage forests cooperatively and equitably;
- the health of the forest actors, cultures, and the forest is acceptable to all stakeholders; and
- yield and quality of forest goods and services are sustainable.

The experience of CIFOR and the many regional processes attempting to develop and implement operational SFM C&I make two things clear. First, there is no one, neat definition of SFM that can be applied everywhere, although there are a number of core common elements. Second, "SFM is to a great extent a social issue. . . . In other words, forest policy must be part of comprehensive economic policy as expressed through agricultural policy, land use and population policy, tax codes, forest and recycling policy and other approaches to managing demand and supply" (Funston 1995; see also Folke et al. 2002). Kaimowitz (2003) notes that past efforts to promote sustainable forest management did not focus enough on macroeconomic, agricultural, infrastructure, finance, and energy policies that slowed progress in implementation of the SFM paradigm. In this respect, Canadian initiatives on SFM (such as partnership in forests, models forests, and so on) are a promising tool for implementing sustainable forest management (e.g., Collate 2003; Weaver 2003).

Despite negative trends in some regions, the world's forests still demonstrate considerable vitality and resilience and retain the potential to meet growing human needs—if, that is, they are managed more sustainably. The recent history of boreal forests, for example, has demonstrated their strong regeneration capacity despite high levels of natural and anthropogenic disturbance. The total area of closed forests in Russia has registered a net increase of about 80 million hectares over the past 40 years, even though about 55 million hectares were clear-cut during this period (Shvidenko and Nilsson 2002). Studies also show that tropical forests can regenerate when agriculture in an area is abandoned (such as around the ancient city of Angkor in Cambodia, on Mexico's Yucatan peninsula, and in old sugarcane fields in Venezuela) (Richards 1996; Hamilton 1976).

A number of countries and regions have undergone periods of extensive forest loss but then developed solid legislative, economic, and social backgrounds for the transition to sustainable forest management. For example, Europe lost 50–70% of its original forest cover, mostly during the early Middle Ages, and North America lost about 30%, mostly in the nineteenth century (WRI et al. 1996; Chiraz 1998; UNECE 1996). Forest policies and economic development in the twentieth century in these regions, however, have encouraged forest restoration and plantation development, restoring a significant part of the forest cover in both Europe and North America. Yet many forests in these regions continue to decline in quality, are becoming increasingly fragmented, and suffer the impacts of industrial pollution.

In many parts of the developing world, deforestation continues to accelerate in tandem with poverty and high levels of population growth. For these regions, the transition to sustainable forest management is a much greater challenge. And the stakes for the global community are much higher: if tropical developing countries must wait until they reach the levels of economic development—and deforestation—of Europe before making this transition, a large percentage of known terrestrial species may become extinct in the meantime due to the disproportionate number of species found within their forests (Rodrigues et al. 2003).

This chapter assesses the condition of the world's forest ecosystems and trends in the services they provide for human well-being. It begins with a presentation of some key definitions and a brief discussion of some of the data and methodological issues the authors confronted in compiling and assessing the information presented. The chapter then reviews forest and woodland extent, condition, and changes. Subsequent sections assess the services provided by forest ecosystems and the direct and indirect drivers of changes in forest and woodland cover and condition. Finally, the chapter reviews the implications of these changes for human well-being. This chapter should be read in conjunction with Chapter 9 of this volume, on timber, fuel, and fiber, and Chapter

8 of the *Policy Responses* volume, on wood, fuelwood, and non-wood forest products.

21.2 Definitions, Methods, and Data Sources

The choices of definitions, methods, and data sources made for this chapter have a profound influence on the presentation of statistics and findings on global forest conditions and trends. This section therefore discusses the choices made, the rationale behind them, and the strengths and limitations of the definitions, methods, and sources used. These should be borne in mind when reviewing the data presented in subsequent sections.

21.2.1 Definitions of Forest and Woodland

There is no single, agreed definition of "forest," due to varying climatic, social, economic, and historical conditions. The situation is complicated by the fact that for many governments, "forest" denotes a legal classification of areas that may or may not actually have tree cover.

A variety of definitions of forest are in use. For example, the *Global Biodiversity Outlook* (Secretariat of the Convention on Biological Diversity 2001) defines forests as "ecosystems in which trees are the predominant life forms" and notes that a more precise definition than this remains surprisingly elusive because trees occur in many different ecosystems, at different densities, and in different forms. Most definitions refer to canopy or crown cover, which is essentially the percentage of ground area shaded by the crowns of the trees when they are in full leaf. The U.N. Framework Convention on Climate Change process has adopted a nationally defined threshold of between 10% and 40% canopy closure. A number of remote sensing products of the last decade (MODIS, GLC-2000) have introduced other approaches (see edcddac.usgs.gov/glcc/glcc.html, glcf.umiacs.umd.edu/data/lanfcover/data.shtml, www.gvm.sai.jrc.it/glc2000/defaultGLC2000.htm, duckwater.bu.edu/lc/dataset). Estimates of forest or woodland area thus vary widely depending on the definitions used. The precise definitions employed should therefore be borne in mind when comparing forest cover data provided by different institutions.

This chapter mainly follows the definition of forest used by FAO's *Global Forest Resources Assessment 2000* (FAO 2000, 2001c). The FAO definition covers ecosystems that are dominated by trees (defined as perennial woody plants taller than 5 meters at maturity), where the tree crown cover (or equivalent stocking level) exceeds 10% and the area is larger than 0.5 hectares (FAO 2000, 2001b, 2001c). The term includes forests used for production, protection, multiple use, or conservation, as well as forest stands on agricultural land (such as windbreaks and shelterbelts of trees with a width of more than 20 meters) and plantations of different types. It also includes both naturally regenerating and planted forests. The term excludes stands of trees established primarily for agricultural production, such as fruit tree plantations, and trees planted in agroforestry systems (but rubber and cork oak stands are included). Billions of trees outside the forest in cities, along roads and rivers, on farms, and so on are not included in the two categories just described.

The threshold of 10% is crucial in this definition. In many countries, "forest" is typically defined as areas with substantially higher levels of canopy closure, for example 30–40%, depending on age, in Russia (FFSR 1995) and 60% in South Africa (Scholes 2004). In the classification of forests introduced by UNEP-WCMC, all forest classes have a minimum threshold of 30% except for the class including sparse trees and woodlands, for which canopy closure is from 10% to 30% (UNEP-WCMC 2004). Another controversial feature of the FAO definition is its inclusion of "temporarily unstocked areas" (clear-cuts, burnt areas, and so on) as forest. This means that a country may have logged or burned most of its forest, but—unless it converts the area to another officially noted productive land use—it will appear to have retained the same forest area as before (WRM 2002; Wunder 2003). These definitional issues generate some problems with analysis of FRA-2000 data and the conclusions that flow from that analysis.

Nonetheless, the FAO definition has been adopted because it is the first consistent definition of forests to be applied globally. A global assessment such as this one obviously requires a consistent global definition of "forest" and a global dataset that adheres to that definition. The strengths and limitations of FRA-2000 are summarized in Box 21.2.

FRA-2000 defines "closed forests" as those with a canopy cover of more than 40% (and it is this class of forest that is incorporated into the system maps and analysis throughout this volume). "Open forests" have a canopy cover of between 10% and 40%. "Fragmented forests" (which are not quantitatively defined by FRA-2000) refer to mosaics of forest patches and non-forestland. Closed forests, open forests, and fragmented formerly closed forests, as a rule, are ecologically substantially different from one another.

In this chapter, "woodland" refers to the type of land cover characterized by trees and shrubs: "other wooded land." Other wooded land, or OWL, is defined by FRA-2000 as land with a tree crown cover (or equivalent stocking level) of 5–10% of trees able to reach a height of 5 meters at maturity, a crown cover of more than 10% of trees not able to reach a height of 5 meters at maturity (such as dwarf or stunted trees), or shrub and bush cover of more than 10%. OWL excludes areas with the tree, shrub, or bush cover just specified but of less than 0.5 hectares and width of 20 meters, as well as land predominantly used for agricultural practices (FAO 2000, 2001c). Trees growing in areas that do not meet the forest and OWL definitions are excluded (FAO 2001c). Such trees are included in assessments of "trees outside forests."

Plantations are defined by FRA-2000 as "forests established by planting or/and seeding in the process of afforestation or reforestation, and consisting of introduced species or, in some cases, indigenous species." There is a substantial difference between plantations in the tropics and those in temperate and boreal countries. Broadly, there are two different types of plantations: short-rotation, fast-growing species plantations (such as *Eucalyptus* and *Pinus*) and plantations of long-rotation, slow-growing species of valuable hardwoods. In the tropics, important hardwood plantation species include teak (*Tectona grandis*) and rosewood (*Dalbergia spp.*). Common hardwood plantation species in the temperate zone include oak (*Quercus spp.*), ash (*Fraxinus spp.*), poplar (*Populus spp.*), and walnut (*Juglans spp.*). This is not, however, a hard-and-fast distinction, since some medium-rotation softwood saw-log plantations (in South Africa, for instance, and New Zealand) also produce valuable timber.

21.2.2 Variations in National-level Forest Information

Thirty years ago, it was noted that "more is known about the surface of the moon than about how much of the world's surface is covered by forests and woodlands" (Persson 1974). Since then, the quantity and quality of available information has improved in some countries but has declined in others and overall remains inadequate. Information about the status of forest inventories in

BOX 21.2

Strengths and Limitations of the *Global Forest Resources Assessment 2000* (FAO 2001c; Matthews 2001; R. Persson, personal communication, 2004)

FRA-2000 is the most comprehensive, globally consistent assessment of global resources available and is the basis for the assessment presented in this chapter. The definitional and methodological choices made by FRA-2000, however, substantially affect the conclusions of the assessment and are therefore important to understand and take into account.

FRA-2000 presents new estimates of global forest cover in both 2000 and 1990. The *1990 FAO Global Forest Resources Assessment* (FRA-1990) used different crown-cover thresholds for industrial (20%) and developing (10%) countries that hindered consistent global analyses and comparisons. FRA-2000 uses a consistent threshold of 10% for all countries and has adjusted the FRA-1990 estimate of forest cover using the 10% global threshold as well. As a result, the FRA-2000 estimate of 1990 forest cover—the baseline from which changes in forest cover are calculated—has been revised upward, to 3.95 billion hectares from 3.44 billion hectares, a 15% increase over the original estimate made in 1990, with the biggest revisions occurring in industrial countries.

In many regions of the world, the use of 10% crown cover as a minimum threshold conflicts with scientific definitions of "forest" as a vegetation type as well as with traditional use and understanding of the term. While the need for a consistent global definition of "forest" is clear, the rationale for setting the threshold at such a low percentage is contested by many, and a number of other FRA methodological decisions remain questionable. The definition of plantations as "forest," for example, affects estimates of net forest loss in the tropics and obscures the actual rates of natural forest loss.

While most industrial countries have relatively good forest cover data, there are serious problems with the way forest cover data are reported in Canada and Russia. Because these two countries account for more than 65% of all forests in industrial countries, these national methodological inconsistencies skew results for the entire temperate and boreal region.

FRA-1990 used mathematical models to compensate for poor data availability in developing countries. The FRA-2000 analysis, however, is based on national forest inventory data supplemented by remote sensing information and expert opinion. While many national data used by FRA-2000 were obsolete or incomplete, the remote sensing survey used to supplement national data relied on images covering only 10% of total tropical forest area, focusing on the same randomly selected 117 sites surveyed in 1990. Deforestation, however, is not randomly distributed—it is highly concentrated along roads and rivers (Stokestad 2001)—and it is therefore arguable that a 10% sampling rate is insufficient to identify accurately how much forest survives intact and how much is being lost.

different countries can be found in the forest resources assessment publications of FAO (FAO 1982, 1993, 1995b, 1999a, 2000, 2001a, 2001b, 2001c). (The text of this section is largely based on Janz and Persson 2002.)

Most industrial countries have some kind of forest inventory. In 1990, 18 of 34 of these countries (containing 76% of the forest area in industrial countries) derived their forest area information from sampling-based national forest inventories, some of which were quite old. In the other 16 countries, information had been compiled by aggregating local inventories, which were usually carried out for forest management purposes (FAO 1995a). Such information contains unknown errors and is usually biased, as the aggregation method is known to produce significant underestimates of volumes and increment. A good example can be taken from Germany, where at the end of the 1980s a sampling-based national forest inventory was introduced that reported a stock-per-hectare increase from 155 cubic meters per hectare in 1985 to 298 cubic meters in 1990 (ECE/FAO 1985, 1992). Overall, it has been noted that the situation in several industrial countries (particularly in the former Soviet Union) is less than satisfactory for national and international forest policy development and implementation (FAO 2001d).

For developing countries, the quality of forest resources information also varies greatly. FRA-1990 reported that all but seven developing countries had at least one estimate of forest cover dating from between 1970 and 1990, usually based on remote sensing. Only 25 out of 143 countries had made more than one assessment. On average, the figures supplied to FAO were about 10 years old (FAO 1995a). FRA-2000 (FAO 2001d) reports that only 22 countries (of 137) have repeated inventories, 28 countries have no inventory, and 33 have a partial forest inventory; 34 have an inventory from before 1990 and 43 have one from after 1990. More than half the inventories used by FAO were either more than 10 years old or incomplete. Very few developing countries have up-to-date information on forest resources, and fewer have a national capacity for generating such information.

Knowledge of area and condition of forests in many countries does not seem to be improving, and in many cases it is actually declining. Additional issues of concern relate to the quality rather than the quantity of forestry-related information:

- There is often a strong interest in new technologies and the production of "showpiece" maps. Modern forest inventories are sometimes only forest mapping exercises, which do not contain all the information needed for sustainable forest management.
- There is a great deal of reliance on remote sensing technologies. However, remote sensing cannot provide information in many areas for which there is a need for better information, such as forest ownership and tenure, protection status, purpose and success rate of plantations, biodiversity, and production and consumption of forest-derived services.
- Few forest inventories are undertaken as part of regular monitoring schemes—most are one-time undertakings. As a result, comparable inventory information for different time periods is frequently unavailable.

The demand for forest information is increasing (for example, in response to the Intergovernmental Panel/Forum on Forests Proposals for Action and to report to international conventions), but there is no corresponding allocation of resources. The funds available for forest inventories are actually decreasing in many countries due to budget cuts and structural adjustment policies. For example, 20–30 years ago forest inventories in many countries were supported financially by international agencies, including FAO. Today hardly a single inventory of this type is being supported financially.

The trend in reliability of national data on forests for countries of Africa, Asia, and Latin America and the Caribbean can be estimated by classification of countries as having low (L), medium (M), or high (H) quality data (Persson 1974; FAO 1993; FAO 2001c). National inventory methods have been used as the main criterion for data quality classes. The ratio L:M:H (in percent to total amount of countries included in the survey) was 27:63:10 in 1970, 23:56:21 in 1990, and 11:25:64 in 2000. While there is an improving trend, progress has been slow, despite the increasing capabilities and utilization of remote sensing and other modern techniques. And some countries, such as Gabon and Côte d'Ivoire, have been covered by extensive inventories in the past but are now placed in the ''low'' category. Indeed, across Africa the number of countries in the ''low'' category increased between 1970 and 1990. The trend is more positive in Asia, but some of this improvement may due to the use of rapid assessment remote-sensing inventories.

21.2.3 Data Collection Methodology for FRA-2000

The FAO FRA process aims to collect statistical information on forests directly from countries. Information on temperate and boreal zones in industrial countries is collected through questionnaires. The national figures are then adjusted to fit FRA forest definitions. The data in FRA for developing countries, however, result from a dialogue between FRA and the countries, which included a number of steps: countries are requested to supply information; independent information (such as remote sensing) is used to corroborate the information received; estimates and outputs (partly by countries) are produced; and validation by and dialogues with countries are held. For FRA-2000, over 1,500 national and international reports were analyzed, and the information obtained was reclassified to fit FRA definitions in consultation with the providing countries.

It is evident, however, that official national statistics have many shortcomings following from weaknesses in national inventory methods and the varying political, administrative, and economic conditions of individual countries. In its analysis of the reliability of FRA-2000 data, FAO has pointed out that global results cannot be more accurate than national data and that all gaps and uncertainties of countries' statistics inevitably affect the FRA-2000 conclusions (FAO 2001c:350–51). Improvement in the information provided by international assessments such as FRA requires improvement in the information supplied at the national level. By using national statistics, however, FRA-2000 allows for ongoing improvement in the assessment process, whereby new information can be incorporated as it becomes available.

21.2.4 Global Forest Mapping Methodologies

In an effort to provide spatial definition of forests, the MA used two global maps produced by FRA-2000: the FRA-2000 global forest cover map (see Figure 21.1 in Appendix A) and the FRA-2000 global ecological zone map (see Figure 21.2 in Appendix A). In this assessment, these two datasets have been combined with a global continent map (ESRI 1998), in order to demonstrate forest class area geographically by continent and ecoregion. For the global summary statistics of the MA, the forest system was calculated from >40% forest cover classes of the Global Land Cover 2000 dataset.

The GLC2000 land cover database has been chosen as a core dataset for the MA—in particular, as a main input dataset to define the boundaries between systems such as forest, grassland, and cultivated systems. GLC2000 used the VEGA2000 dataset, providing a daily global image from the vegetation sensor onboard the SPOT4 satellite from November 1999 to December 2000. The GLC2000 dataset identified globally a total of 10 tree cover types: broadleaf evergreen; broadleaf deciduous (closed); broadleaf deciduous (open); needle-leaved evergreen; needle-leaved deciduous; mixed leaf type; regularly flooded fresh; regularly flooded saline; mosaic: tree cover/other natural vegetation; and burnt. Forests were identified as having a minimum of 15% tree cover and 3 meters height. Closed forests were defined as having more than 40% tree cover. When aggregated, forest areas in the GLC2000 compare spatially well with the forest areas defined in the FRA2000. (For further details of GLC2000, see Chapter 2.)

The forest map in Figure 21.1, developed using coarse resolution satellite imagery, relied mainly on the Global Land Cover Characteristics Database. Source data for the forest map were drawn from the 1995–96 dataset and consisted of five calibrated advanced very high resolution radiometer bands and a normalized difference vegetation index (FAO 2001c). Results of an accuracy assessment showed that overall map accuracy is approximately 80%. Closed forests are more accurately mapped than the average accuracy, with open and fragmented forests less accurately mapped and other wooded lands least accurately mapped (FAO 2001c).

The ecological zone map in Figure 21.2 was developed using national and regional maps of potential vegetation and climate data. A globally consistent classification was adopted, based on the Köppen-Trewartha climate system in combination with natural vegetation characteristics. A total of 19 global ecological zones have been defined and mapped, ranging from the evergreen tropical rain forest zone to the boreal tundra woodland zone (FAO 2001c).

Although this chapter uses some estimates of forest area derived from these two maps, it should be noted that FRA-2000 only uses these maps to indicate the spatial distribution of forests and does not use data derived from the maps in its statistics on forest extent and cover.

Remote sensing methods are becoming an important tool for improving data and knowledge on the world's forests in the future. New and planned satellite sensors appear to be very promising in this regard, and several global initiatives (GTOS, GOFC-GOLD) are focusing on their further development. Experiences over the last decade, however, illustrate a number of problems with the estimation of forest cover and extent from space. (See Box 21.3.)

21.3 Condition and Trends in Forest and Woodland Systems

21.3.1 Forest Area

FRA-2000 estimates the total area of global forests at 3,869 million hectares (0.6 hectares per capita), or about 30% of the world's land area (see Table 21.1), with closed forests accounting for 3,335 million hectares. (Table 21.1, unlike FRA-2000, divides Russian forests into their European and Asian parts based on national statistics in order to give a more accurate assessment of the relative areas of forest on the European and Asian continents.) This can only be taken as an approximate estimate, however, due to the methodological problems that the FAO faced with respect to data weaknesses and inconsistencies among countries, as described in the preceding section. As noted there, national data for many developing countries are scarce and unreliable, and inconsistencies also exist for some industrial countries. Data for Canada, for example, are aggregated from provincial sources and report only ''productive forestland,'' while ''unproductive forests'' are reported by FRA-2000 as other wooded land, even though many of them meet the FAO definition of forest. This anomaly resulted

BOX 21.3

Forest in Recent Global Land Cover Assessments Using Remote Sensing Methodologies

During the past decade, a number of attempts have been made to estimate forest area in the framework of global land cover assessments using various remote sensing methodologies. The major features of four satellite-based 1-kilometer land cover products in wide use by the international scientific community (McCallum et al. 2004) are compared and analyzed here.

The International Geosphere-Biosphere Program product (version 2.0) is derived from advanced very high resolution radiometer data from April 1992 to March 1993. This methodology employed a multi-temporal unsupervised classification of a normalized difference vegetation index with post-classification refinement using multi-source data. In total, 17 land cover classes were considered (USGS 2003).

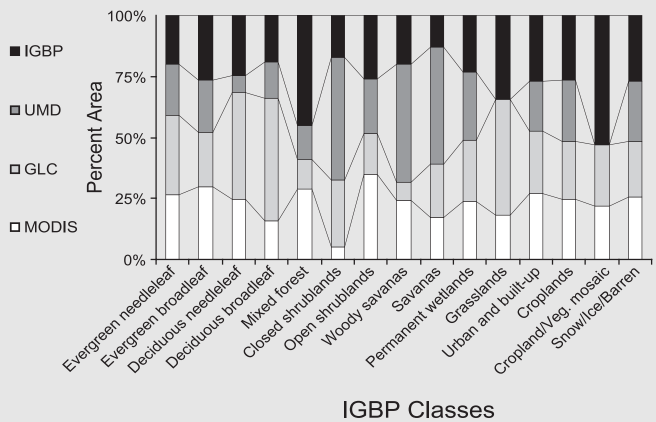
The University of Maryland product used the IGBP AVHRR dataset, utilizing all five AVHRR channels as well as the NDVI, to derive 41 multi-temporal metrics from monthly composites to represent the phenology of global vegetation. UMD used a supervised classification tree method, resulting in a total of 14 land classes (Hansen and Reed 2000).

Global Land Cover 2000 is based on daily mosaics of four spectral channels and NDVI from VEGETATION-SPOT 4 imagery acquired from November 1, 1999, to December 31, 2000; data from other sensors have been used to solve specific problems. A total of 22 classes were produced (JRC 2003).

The MODIS-Terra product utilized monthly composites of eight input parameters from October 2000 to October 2001. The classification, which resulted in 20 land cover classes corresponding to IGBP classes, was produced using a supervised approach with a decision tree algorithm (MODIS 2002).

Land classifications differed between some of these remote sensing methodologies. McCallum et al. (2004) carried out a comparison of these four products, applying physiognomic aggregation of different land classes (cf. Hansen and Reed 2000) using the IGBP classification (with 17 classes) as a base. Differences in estimated areas of the same classes are significant. (See Figure.)

All these remote sensing methodologies contain forest classes. Comparisons of the satellite-derived data and FRA-2000 are presented in the accompanying Table. Area estimates by all four remote sensing methodologies are less than those by FRA-2000, averaging −26.4% and varying from −13.5% (GLC 2000) to −43.6% (UMD, although in this case the large difference is additionally affected by incompatible classifications). The four remote sensing estimates, when compared for each aggregated IGBP class, vary from 12% to 74%. The reasons for the significant underestimates of forest area by these remote sensing methodologies compared with FRA-2000 are not completely clear. The remote sensing underestimates can probably be explained by the coarse resolution of the remote sensing technology used, fragmentation of forests in many regions, lack of satisfactory ground truth data for proper validation and verification of the remote sensing data, and the use of different classifications. By contrast, in this chapter's attempt to use the FAO global forest map the total area of the world's forests was estimated to be 4,356 million hectares—that is, about 12% more than the total provided by the FRA-2000 data.



Comparison of Forest Classes Derived from Four Global Land Cover Projects Using the IGBP Classification Terminology. The areas are presented as the percentage of an individual class to the total area of all forest classes inside of each product. (McCallum et al. 2004)

Forest Area: Comparison of Four Global Remote Sensing Land Cover Products and FRA2000 Using IGBP Classes 1–5 (McCallum et al. 2004)

IGBP Forest Classes	GLC-2000	IGBP	MODIS	UMD	Average	Range of Variation from Average
	Area by RS Global Products (*million hectares*)					(*percent*)
1 – Evergreen needleleaf	943	480	598	521	636	33.2
2 – Evergreen broadleaf	1,281	1,342	1,502	1,108	1,308	12.4
3 – Deciduous needleleaf	377	193	201	56	207	63.6
4 – Deciduous broadleaf	627	221	172	174	298	73.9
5 – Mixed forests	320	981	696	323	580	55.2
Total	3,548	3,217	3,168	2,182	3,029	19.5
	(*percent*)					
Difference with FRA2000	–13.5	–21.6	–23.7	–46.8	–26.4	

in underreporting of more than 170 million hectares (40%) of Canadian forestland. With this and similar adjustments, the global forest cover corresponding to the FAO definition would probably increase by about 5%.

Forests are not distributed evenly across the globe, as Figures 21.1 and 21.2 indicate. Although average forest cover on all continents except Antarctica exceeds 20%, vast territories are either completely bereft of forests or have negligible forest cover. FRA-2000 estimated that 56 countries have an average of only 3.9% forest cover. On the other hand, the six biggest forest countries—Russia, Brazil, Canada, the United States, China, and Australia—contain about 56% of the world's forests.

Table 21.1. Forest Area by Region in 2000 (FAO 2001c, modified for Europe and Asia; see explanation in text)

Region	Land Area	Forest Area: Natural Forests	Plantation	Total	Forest Coverage
	(million hectares)				*(percent)*
Africa	2,978	642	8	650	22
Asia	4,362	1,105	120	1,225	28
Europe	983	334	28	362	37
North and Central America	2,137	532	18	549	26
Oceania	849	194	3	198	23
South America	1,755	875	10	886	51
World total	**13,064**	**3,682**	**187**	**3,869**	**30**

Note: In this chapter, Russian forests are divided into European and Asian parts based on national statistics.

The area of the world's forests estimated using satellite-based methods is 4,356 million hectares (see Table 21.2), which is close to the recent estimate made by the UNEP World Conservation Monitoring Centre—4,540 million hectares (UNEP-WCMC 2002). The total area of closed forests is estimated at 2,860 million hectares (about two thirds of the total), with major areas in Asia, North America, and South America. The different values derived from FRA2000 and satellite data are mostly due to the different national thresholds of closed forests (in Russia, for instance, forests are classified as closed if canopy closure is more than 25%).

The threshold used for national inventories substantially changes estimates of forest area, as is clearly illustrated in Figure 21.3. Nonetheless, estimates of the extent of the world's forests are of the same order of magnitude. The satellite-based total area of global forests is only 11% more than FRA-2000 data in Table 21.2. The total area of global forests plus OWL is estimated to be 5,576 million hectares (about 42% of Earth's land area), which is very close to the corresponding FRA-2000 estimate of 5,532 million hectares.

The estimate in Table 21.2 for the area of tropical closed forests (1,229 million hectares) is in the range of previous estimates, such as those of IUCN at 1,140 million hectares (Collins et al. 1991; Sayer et al. 1992; Harcourt and Sayer 1996), project TREES at 1,165 million hectares (Mayaux et al. 1998), and Achard et al. (2002) at 1,116 million hectares for 1997, without Central America and Oceania. The FRA-1990 estimate was 1,298 million hectares (FAO 1996).

Of the total area of 1,494 million hectares of open and fragmented forests in Table 21.2, more than half (53%) is situated in tropical ecoregions and about 22% is in the boreal zone. A significant part of these forests in the tropics consist of sparse forests in dryland areas and degraded forests. By contrast, the majority of

Table 21.2. Forest Area by Biome and Continent (FRA 2000 Forest Cover Map; FRA 2000 Global Ecological Zone Map; global continents derived from ESRI world map)

Biome	Africa	Asia	Europe	North and Central America	Oceania	South America	Total
				(million hectares)			
Closed forests							
Polar	0	2	1	3	0	0	6
Boreal	0	495	156	295	0	0	945
Temperate	0	97	114	237	13	7	471
Sub-tropical	2	91	11	85	19	6	212
Tropical	274	222	0	77	46	609	1,229
Subtotal	*277*	*908*	*282*	*696*	*77*	*622*	*2,862*
Open and fragmented forests							
Polar	0	5	3	6	0	0	15
Boreal	0	158	46	109	0	0	313
Temperate	0	71	101	47	4	5	226
Sub-tropical	6	49	18	36	14	18	141
Tropical	344	133	0	26	30	264	798
Subtotal	*350*	*415*	*168*	*225*	*48*	*287*	*1,494*
Total forests							
Polar	0	7	4	9	0	0	21
Boreal	0	653	202	404	0	0	1,258
Temperate	0	168	215	284	17	12	697
Sub-tropical	8	140	29	121	33	24	353
Tropical	618	355	0	103	76	873	2,027
Total	**627**	**1,323**	**450**	**921**	**125**	**909**	**4,356**

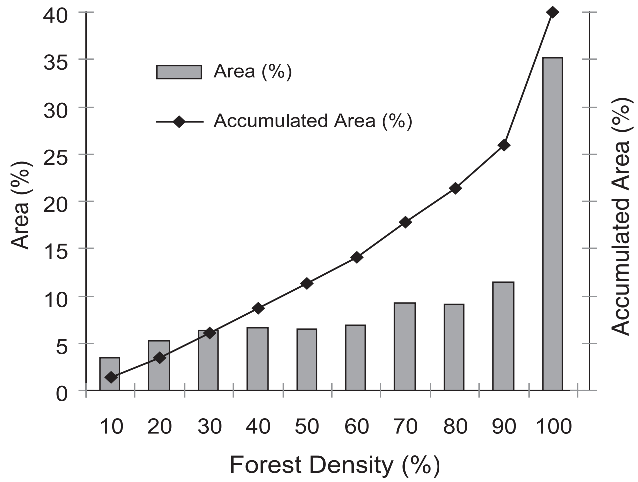


Figure 21.3. Distribution of World's Forests by Canopy Closure

boreal open forests are naturally sparse woodlands in the transition belt of the taiga-tundra ecotone.

The estimate derived from satellite data of the global area of other wooded land is 1,220 million hectares (see Table 21.3), which is 15% lower than the FRA-2000 statistical estimate. OWL plays a significant environmental and protective role in many regions, particularly in the arid tropics and sub-tropics, where it is also known as open savanna woodland. In the boreal ecoregion, areas of OWL are relatively small (about 11% of the total) and often represented by shrubs such as dwarf pine (*P. pumila*) and dwarf birches in Northern Eurasia. Although OWL has a low commercial value, these woodlands have a large and mostly unrecorded value to local people, provide soil and water protection services, and harbor biodiversity across vast landscapes.

Data derived from the FRA-2000 statistical tables and the FRA-2000 global maps are not completely consistent, and making specific area comparisons between these two sources is rather difficult. This is largely due to the different compilation methods used. In particular, differences between the two methods for North America and Oceania are noticeable. In the case of North America, the reported forest cover for Canada and the United States both appear to refer to productive or commercial forest cover only, as mentioned earlier. Therefore, the FRA-2000 forest cover map identifies a greater forest cover than is reported in the country statistics. In the case of Oceania, the forest map underestimates the amount of forest cover compared with the statistics. One likely reason for this is the lack of good satellite imagery (due to persistent cloud cover) preventing the mapping of several Pacific islands (FAO 2001c). In addition, differences in classification between open and fragmented forest and other wooded land may be a factor.

21.3.2 Distribution by Aggregated Forest Types (Ecological Zones)

Different global classifications of the world's forests by forest type are generally largely incompatible. The classification by UNEP-WCMC includes 26 aggregated forest types—15 in tropical forests and 11 in non-tropical biomes (UNEP-WCMC 2004). Based on criteria equivalent to Köppen-Trewartha climatic groups, FRA-2000 considered five domains (biomes)—tropical, subtropical, temperate, boreal, and polar, which are divided in 20 global ecological zones (FAO 2001c, Table 47–2). The latter classification is used in this section, and distribution estimates are based on the remote sensing data sources rather than the FRA-2000 statistical datasets.

Three quarters of the world forests is located in two biomes—tropical (46%) and boreal (29%). Tropical rain forest is the most extensive forest type in the world, constituting 26% of global forest area and nearly 60% of tropical forest area. Most rain forests are in South America (582 million hectares), Africa (270 million hectares), and Asia (197 million hectares). Tropical rain forests are closed-canopy evergreen broadleaf forests that generally require continual temperatures of at least 25 Celsius and annual rainfall of at least 1,500 millimeters (Richards 1996). Tree diversity in tropical rain forests is very high, with often more than 100 tree species per hectare.

Tropical moist deciduous forests cover some 510 million hectares. They develop in areas with a dry season of three to five months, and they vary from closed forests to open savanna forests, depending on dry-season length, human pressures, and fire regimes. Only about one third of these forests are closed primary forest areas; the rest are open and fragmented forests, including significant areas of secondary forest created by disturbances such as agricultural clearing and fire. The soils are in general better than in rain forests areas, and human population pressure is therefore higher. In Asia, these forests contain commercially important species like teak (*Tectona grandis*) and *sal* (*Shorea robusta*). In tropical dry forests the dry season is longer than in the moist deciduous (open tropical) forests. Remaining areas of tropical dry forests are relatively small, consisting mostly of open forest.

Table 21.3. Area of Other Wooded Land by Biome and Continent (FRA 2000 Forest Cover Map; FRA 2000 Global Ecological Zone Map; global contents derived from ESRI world map)

Biome	Africa	Asia	Europe	North and Central America	Oceania	South America	Total
				(million hectares)			
Polar	0	5	3	6	0	0	15
Boreal	0	45	9	36	0	0	90
Temperate	0	34	22	3	3	4	67
Sub-tropical	22	78	6	7	25	27	164
Tropical	492	38	0	5	46	289	871
Total other wooded land	*514*	*207*	*39*	*67*	*74*	*319*	*1,220*
Total forest	*627*	*1,323*	*450*	*921*	*125*	*909*	*4,356*
Total	**1,141**	**1,530**	**489**	**988**	**199**	**1,228**	**5,576**

The temperate and boreal forests occur from the sub-tropics to the arid steppes and sub-Arctic, with the northernmost growing at 72°30′ in central Siberia (Abaimov et al. 1997) at an annual average temperature of −15° to −17° Celsius. They are mostly distributed in 55 industrial countries (in Europe, the former Soviet Union, North America, Australia, Japan, and New Zealand). Detailed and reasonably reliable information concerning these forests is available (FAO 2000). The total area of forest in these countries was estimated to be 1,914 million hectares, supplemented by an additional 795 million hectares of other wooded lands. Thus the total area of forest and other wooded land is estimated to be 2,478 million hectares, which accounts for 47% of global tree cover. More that one third (38%) of the total in these zones is located in the former Soviet Union, 29% in North America, 9% in Europe, and 25% in Australia, Japan, and New Zealand. On average, these countries have 1.3 hectares of forest per capita—about double the global average, although there is great variation between countries (from nearly none in Malta and Azerbaijan to 6 hectares per capita in Russia and 31 hectares per capita in Australia). These statistics do not include China, which has significant areas of temperate and boreal forests—30% and 8% respectively of the country's total forest area of 163.5 million hectares.

Countries of these biomes accounted for in the *Temperate and Boreal Forest Resources Assessment* contain 47% of predominantly coniferous forest (mostly genera *Pinus, Picea, Larix, Abies*), 26% of predominantly broadleaf forest (many genera, including *Populus, Betula, Quercus, Fraxinus, Tilia*), and 27% of mixed coniferous and broadleaf forests. Other forests types (bamboos, palms, and so on) cover small areas in Japan. Coniferous forests serve as a major source of global industrial wood, and the broadleaf forests include a number of high-value commercial species. (See Chapter 9.)

21.3.3 Wood Volume and Biomass

Wood volume, woody biomass, and total live biomass are important indicators of the potential of forests to provide various products and services, including carbon sequestration. Based on available information from 166 countries (about 99% of the world's forest area), FRA-2000 estimated the total global standing volume (aboveground volume of all standing trees, living or dead, with diameter at breast height over 10 centimeters) to be 386 billion cubic meters and the global aboveground woody biomass to be 432 billion tons (dry matter), which gives average values of 100 cubic meters and 109 tons per hectare, respectively. IPCC (2000) estimated the total carbon stock of vegetation in forest to be 359 billion tons of carbon. These data vary greatly over continents and countries. Average standing volume, for example, varies from about 60 cubic meters per hectare in Oceania and Asia to 125 cubic meters in North and South America, while the ratio of aboveground biomass (tons) to standing volume (cubic meters) varies from about 0.5 in Europe to 1.6 in South America (FAO 2001c).

21.3.4 Extent of Natural Forests

There are numerous ways of characterizing the degree of ''naturalness'' of forests—old growth, ancient, intact, frontier, natural, secondary, modified, and so on—and although there are no consistent, agreed definitions and information with which to classify forests in this manner is poor, FAO has defined natural forests as forests composed of indigenous trees regenerated naturally (FAO 2000c, 2002b).

Although FRA-2000 considered all forests except plantations to be ''natural'' (FAO 2001c), FRA-2005, which is currently under preparation, considers four classes of decreasing ''naturalness''—primary forest, modified natural forest, semi-natural forest, and forest plantations (FAO 2004). Forest inventories as a rule do not characterize forests by their degree of naturalness, however, and so only limited assessments are available.

One attempt to inventory the extent of natural forests by the World Resources Institute identified the global extent of ''frontier forests''—remaining large, intact natural forest ecosystems big enough to maintain all of their biodiversity (Bryant et al. 1997). These represent only 40% of the planet's remaining forests, and 39% of these are threatened by logging, agricultural clearing, and other human activities. Seventy-six countries were found to have lost all of their frontier forests, while 70% of what remains lies within three countries (Brazil, Canada, and Russia), and only 3% lies within the temperate zone.

This chapter uses a simplified three-class approach to forest naturalness, limiting the classification to ''natural'' (self-regenerating, generally multi-species, mixed age stands of native species, with a natural disturbance regime); ''semi-natural'' (some degree of human intervention in regeneration, species selection, and disturbance); and ''anthropogenic'' (established or significantly transformed by humans). Using regional expertise and some published sources (e.g., Vorob'ev et al. 1984; Bryant et al. 1997; Atlas 2002) it can be tentatively estimated that about 70% of the world's forests can be considered to be natural, 20% semi-natural, and 10% anthropogenic (half of which are plantations).

21.3.5 Trees Outside of Forests

Trees outside of forests, or TOF, occur in many formations, such as shelterbelts, shade and other elements of agroforestry, roadside plantings, village and urban plantings, orchards, and individual trees on farms and other private land. Although there are no consistent global data on the coverage or extent of TOF, FRA-2000 provides a global review of this, acknowledging the diversity of the multiple functions and benefits (FAO 2001c). For example, about 70% of the land area of Java (Indonesia) has trees but only 23% of this is classified as forest (Persson 2003).

TOF provide important services, including contributing to food security, particularly for rural populations (Auclair et al. 2000; Glen 2000; Klein 2000). In many Asian countries, particularly those with low forest cover, TOF supply the majority of fuelwood (Arnold et al. 2003). For example, more than 75% of fuel production comes from non-forestland (mostly from TOF) in Bangladesh, India, the Philippines, and Thailand, although with significant variation among countries (Bhattarai 2001). Shelterbelts are an important component of agroforestry landscapes in many countries of the northern hemisphere (see, e.g., Yukhnovsky 2003). Quantitative data on TOF are scarce and not comparable, however, since they are mostly limited to regional and national case studies (FAO 2003b), although some counties (such as France, the United States, India, and Bangladesh) have initiated efforts to gather national-scale quantitative information on TOF (FAO 2001c).

21.3.6 Distribution of People in Forest Areas

The current distribution of people living in and adjacent to forest and woodland areas is the result of a long historical process of social and economic development. Significant factors influencing population distribution include topography, degree and direction of landscape transformation, and forest types. Currently, about three quarters of humanity lives in three ecological zones classified as aggregated forest ecoregions (needle-leaved evergreen, closed broadleaf deciduous, and broadleaf evergreen), although a far smaller number actually live in or adjacent to forested areas (CIESIN 2000).

As a rule, more-densely populated regions have less natural forest and more plantations than less populated regions (Persson 2003). Typical examples are China and India, with a combined population of about 2.3 billion and forest area of just 228 million hectares (FAO 2001c). Based on U.N. population statistics, UNEP-WCMC has derived detailed information on the ratio of forest area to people at both the national level and for 12 large regions in 1996 (UNEP-WCMC 2004). The overall global number was 0.7 hectares per person, with a large variation between regions—from 0.07 for Middle East to 5.6 for Russia and 6.5 for Australasia—and by ecological zones. In the tropics, the highest ratio (1.85 hectares per person) was in rain forest areas and the lowest (0.24 hectares per person) in dry deciduous forests (FAO 1993).

Tropical rain forests typically have low human population densities. This is largely because rain forest soils are frequently low in nutrients and therefore unsuitable for continuous agriculture. Although many rain forest areas can support traditional forms of extensive rotational ("shifting") cultivation, and have done so for millennia, this form of agriculture is unable to support high human population densities. In areas with good soils (such as volcanic or sedimentary soils), rain forests have long since been converted to agricultural landscapes.

Forests are a significant source of employment. Global recorded forest-based employment is about 47 million full-time equivalents, 17 million of whom are in the formal sector (ILO 2001; Blombaeck and Poschen 2003). Labor force trends and dynamics vary among countries and regions, but in general forestry sector employment is decreasing. (See Chapter 9.) The forestry sector labor force in Europe and the former Soviet Union, for example, is expected to decrease by 7% during the coming decade (ECE 2003).

21.4 Changes in Global Forest Area and Condition

21.4.1 Parameters of Change

Four basic change processes determine trends in global forest area and are defined for this chapter as follows:

- *Deforestation* is the conversion of forests to another land use or the long-term reduction of the tree canopy cover below 10%.
- *Afforestation* is the establishment of forest plantations on land that, until then, was not classified as forest. It implies transformation from non-forest to forest.
- *Reforestation* is the establishment of forests plantations on temporarily unstocked lands that were considered as forest in the recent past.
- *Natural expansion of forests* means the expansion of forests through natural succession on land that, until then, was under another land use (such as forest succession on land previously used for agriculture). It implies a transformation from non-forest to forest.

Net changes in forested area are a superimposition of these four major processes. While net changes are important to monitor, it is also important to disaggregate exactly what is being lost and what is being gained. A focus on net changes—for example, plantation establishment offsetting natural forest loss, and gains in forest cover in industrial countries offsetting forest losses in tropical developing countries—may obscure the severity of natural forest losses in tropical regions.

Forest degradation and *forest improvement* describe changes in forest condition, but not changes in an area's land use or land cover status. FRA-2000 defined these as changes within the forest, which negatively (forest degradation) or positively (forest improvement) affect the structure or function of the stand or site and thereby lower (degrade) or increase (improve) the capacity to supply ecosystem services (FAO 2001c). As previously noted, though, there is little consensus among definitions of forest degradation and deforestation. Some logged areas, for example, are severely degraded to the point of being virtually devoid of trees and previous ecological characteristics and functions, and many would argue that such areas should be counted as effectively deforested, irrespective of their formal legal or management status.

21.4.2 Changes in Global Forest Cover

Clearing of forests for other land uses, particularly agriculture, has accompanied human development for the whole of documented human history. Historically, deforestation has been much more intensive in temperate regions than in the tropics, and Europe is the continent with the least amount of original forests remaining. As a whole, clearance prior to the industrial era was a slow and steady process over a long period of time. In the more recent past, many countries and regions experienced much higher rates of forest conversion, and many currently industrialized countries experienced deforestation rates in the nineteenth century very similar to those now occurring in many tropical developing countries.

The relationship between agricultural expansion and forest decline has been analyzed, and the following preliminary conclusions emerge: agricultural land is expanding in about 70% of countries, declining in 25%, and is static in 5%; forest area is decreasing in two thirds of countries where agricultural land is expanding, but expanding in the other one third of those countries; and forests are expanding in 60% of countries where agricultural land is decreasing and are declining in 36% of this group of countries (FAO 2003b). A complicated combination of economic and social development factors, levels of agricultural productivity and urbanization, climatic and geographical peculiarities, and countries' previous histories determine rates of deforestation in particular places.

Significant deforestation in tropical forests has been documented for 1990–2000. The total loss of natural tropical forests is estimated for this period at 15.2 million hectares per year (FAO 2001c). Taking into account relatively small natural expansion of tropical forests (+1.0 million hectares a year) and plantations that have been developed at +1.9 million hectares annually, the net change in tropical forest area was estimated by FRA-2000 to be −12.3 million hectares. In contrast, during this period a net increase of forest area was observed in temperate and boreal zones (+2.9 million hectares a year, of which +1.2 million hectares were forest plantations and +1.7 million were due to the change in area of natural forests). In total, then, the net change in global forest area is estimated at −9.4 million hectares per year. (See Table 21.4 and Figure 21.4.)

The net annual change in forest area for 1980–90 was estimated to be −13 million hectares (FAO 1995b) (including losses of 6.1 million hectares per year in tropical moist forests and 3.8 million hectares per year in tropical dry forests), and −11.3 million hectares for 1990–95 (FAO 1997). This would indicate that net global forest loss has slowed down since the 1980s (FAO 2001c). However, much of this is due to increases in plantation forestry, and although the global net change in forest area was lower in the 1990s than in the 1980s, the rate of loss of natural forests remained at approximately the same level.

Table 21.4. Forest Area Changes, 1990–2000, in Tropical and Non-tropical Areas (FAO 2001c)

	Natural Forest					Forest Plantations			Total Forest
	Losses			Gains		Gains			
Domain	Deforestation	Conversion to Forest Plantation	Total Loss	Natural Expansion	Net Change	Reforestation	Afforestation	Net Change	Net Change
					(million hectares per year)				
Tropical	−14.2	−1.0	−15.2	+1.0	−14.2	+1.0	+0.9	+1.9	−12.3
Non-tropical	−0.4	−0.5	−0.9	+2.6	+1.7	+0.5	+0.7	+1.2	+2.9
Global	−14.6	−1.5	−16.1	+3.6	−12.5	+1.5	+1.6	+3.1	−9.4

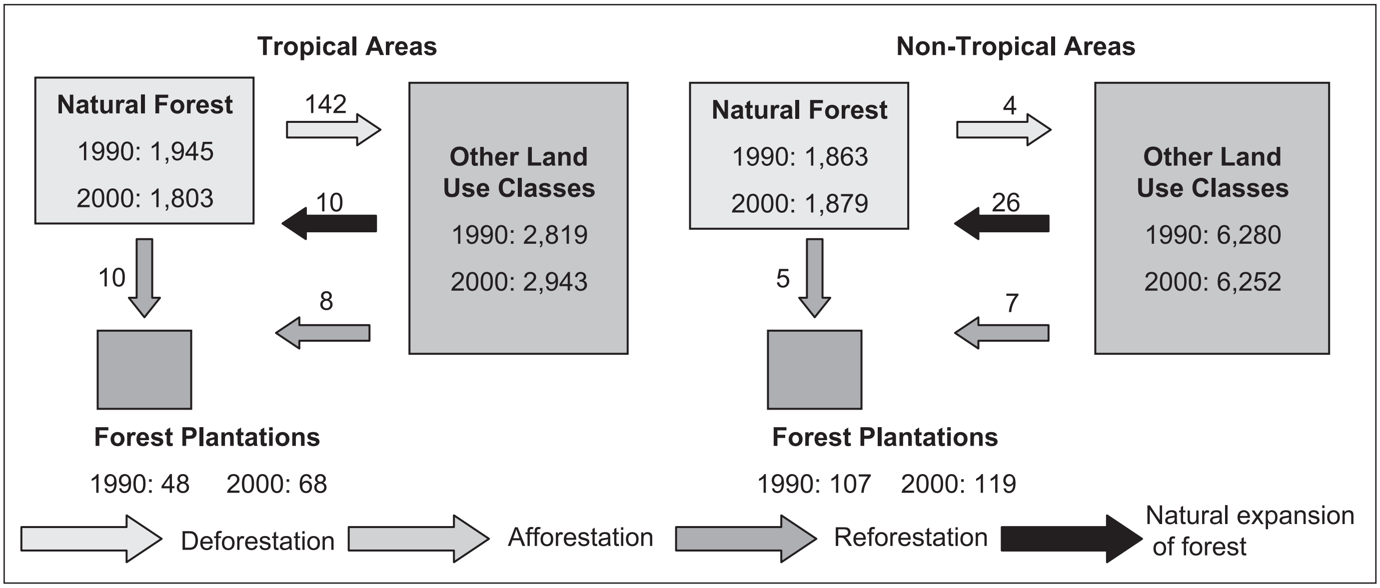


Figure 21.4. Major Change Processes in World's Forest Area, 1990–2000 (in million hectares) (FRA 2000; FAO 2001c)

Matthews (2001), however, reached a different conclusion, finding that in absolute terms, more tropical forest was lost in the 1990s than in the 1980s. According to this estimate, net deforestation rates have increased in tropical Africa, remained constant in Central America, and declined only slightly in tropical Asia and South America. The certainty of this estimate is unknown.

It is likely that deforestation in developing countries has continued since 2000 at practically the same rate as during the 1990s, about 16 million hectares per year, corresponding to 0.84% for the 1990s and 0.80% since 2000. The difference in these estimates is definitely within the uncertainty limits of the techniques used. However, both national inventories and remote sensing data often do not adequately record the regrowth of secondary forests in many areas. If better data on this were available, they would likely reduce the net area change in forest cover for many regions (see, e.g., Faminov 1997).

Recent remote sensing surveys of individual biomes and forest types have reported different, often lower, rates of deforestation than those reported in FRA-2000. The research program TREES (Tropical Ecosystem Environment observation by Satellite) estimated annual losses of humid tropical forests on three major continents between 1990 and 1997 at 5.8 ± 1.4 million hectares with a further 2.3 ± 0.7 million hectares of visibly degraded forests (Achard et al. 2002). This is about one fifth less than the estimates provided from the sources just discussed. However, estimated uncertainties of forest cover were substantial (1,150 ± 54 million hectares and 1,116 ± 53 million hectares for 1990 and 1997 respectively).

On the other hand, a study by DeFries et al. (2002) found that the rate of tropical deforestation actually increased by about 10% from the 1980s to the 1990s, in contrast to the 11% reduction reported by FRA-2000, and supporting Matthews (2001). This is not surprising, since methods vary among different surveys. It must therefore be realized that coarse-resolution remote sensing data still cannot provide detailed reliable information about changes in forest area. Rather, existing published figures provide only estimates of the order of magnitude of forest cover change (DeFries et al., 1995, 2000; Holmgren and Turesson 1998; McCallum et al. 2004).

Trends in deforestation and net changes in forest area vary across regions, although there are many commonalities within major biomes across regions. The major areas with rapid deforestation are currently in the tropics. Africa accounts for over 50% of net recent global deforestation, although the continent hosts only 17% of the world's forests. Ten tropical countries (six of them in Africa) had net annual change in forest areas of more than 3%, and four countries (three in Africa plus Nicaragua) had change rates of 2.5–3.0% between 1990 and 2000 (FAO 2001c). Net change of forest area by continent is presented in Figure 21.5.

Quantitative data on the dynamics of other wooded land are weak. Many national sources reported substantial transformation

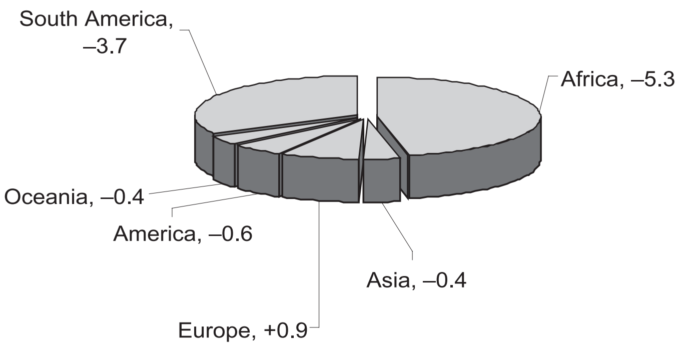


Figure 21.5. Net Change in Forest Area by Continent (in million hectares per year) (FRA 2000; FAO 2001c)

and decline of woodlands, in particular in dry regions, due to extensive conversion for agriculture and excessive harvesting by rural communities (Hassan 2002). Open savanna woodlands in South Africa, for example, have lost about half of their original extent of approximately 42 million hectares (Low and Rebello 1996).

21.4.3 Forest Plantations

Development of forest plantations can have significant impacts on the dynamics of forest areas in some regions. Forest plantations covered 187 million hectares in 2000, with significant regional variation—62% are in Asia and only 17 % in Europe. Ten countries account for 79% of global forest plantation area, and six of these account for 70%. Globally, broadleaf-species account for 40% of forest plantation area, with *Eucalyptus* the principal genus (10% of the global total); coniferous species account for 31%, with *Pinus* constituting 20% of the global total. Genus is not specified in FAO statistics for the remaining 29% (FAO 2001c).

According to national data supplied to FRA-2000, the tropical forest plantation estate has increased from 17.8 million hectares in 1980 to 43.6 million hectares in 1990 and about 70 million hectares in 2000 (Brown 2000; FAO 2001c). However, these and other data on the growth and extent of plantations are not fully comparable due to different definitions, incomplete statistics from different countries, and different approaches to estimation of coverage. For example, Europe and North America are not included in the FAO figures for 1980 and 1990 (FAO 1995a). According to official national data, the annual increase in plantations is 4.5 million hectares globally, of which 3 million hectares are estimated to be successful (FAO 2001c). About 90% of new plantations are in Asia and South America. Although plantations constitute only 5% of global forest cover, they were estimated to supply about 35% of global roundwood in 2000, and it is expected that this figure will increase to 44% by 2020 (ABARE-Jaakko Pöyry 1999; see also Chapter 9).

Other estimates of the rate of increase of plantations are also available. Pandey (FAO 1995a), for example, claimed that the total area of plantations for 1990 in tropics should be reduced by one third (although even this analysis is likely to have overestimated the extent of plantations in some countries such as India) due to peculiarities of the system of accounting for and estimation of plantations. Persson (1995) estimated the planted area in 1990 for all countries in the range of 148–173 million hectares, pointing out that plantation data for China are uncertain, and he estimated annual forest plantation increase in the tropics to have been about 0.5–1 million hectares for the 1970s, 1–1.5 million hectares for the 1980s, and about 2 million hectares for 1990–95. According to Persson (1995), plantations covered nearly 100 million hectares in 1970 and 120 million (100–30 million) hectares in 1980.

Based on socioeconomic analysis, Trexler and Haugen (1995) estimate that the total area of plantation in the tropics is likely to grow by 66.8 million hectares from 1995–2045, including 37.8 million hectares in Asia, 24.5 million hectares in Latin America, and 4.6 million hectares in Africa. Nilsson and Schopfhauser (1995) estimated the global availability of lands suitable for plantations and agroforestry at 345 million hectares. The reliability of these estimates is difficult to assess, however, because they do not consider specifics of many local socioeconomic and social processes, including the potential for expanded plantation establishment to cause social conflicts.

It can be seen from this short review that data on plantations are very uncertain and often contradictory. There are a number of reasons for this. The number of countries assessed for FRA-1980, FRA-1990, and FRA-2000 plantation estimates varied considerably, ranging from only 76 tropical developing countries in 1980 to all 213 countries in 2000. Plantation area is often overestimated if it is calculated from the number of plants produced or planted rather than from actually reforested or afforested areas. The area actually planted is often less than the planned area of plantation, which is often the reported area. Loss of plantations is often not included in national reporting, while the officially planted area is added each year. And finally, there is an inherent bias to exaggerate the success of plantation establishment.

Globally, 48% of forest plantation trees are destined for industrial end-use, 26% for nonindustrial uses, and 26% for unspecified uses (FAO 2001c). Industrial plantations provide raw material for commercial wood and paper products and can generate significant local employment opportunities. (See Chapter 9.) For example, some 1.5 million hectares of plantations in South Africa provide 1.63% of the global supply of pulp, 0.76% of paper, and 0.3% of sawn timber (Bethlehem and Dlomo 2003). Nonindustrial plantations are established to provide soil and water conservation, combat desertification, maintain biodiversity, absorb carbon, supply fuelwood, and rehabilitate fragile and degraded lands. During the last two decades, the major trend has been an increase in plantations established for industrial purposes, which have increased by about 25% since 1980 (FAO 2001c).

Forest plantations have potentially high productivity. On average, mean annual increments of *Eucalyptus* and *Pinus* are in the range of 10–20 cubic meters per hectare per year, but some species (e.g., *E. grandis, E. saligna, P. caribea*) can reach an MAI of up to 50–60 cubic meters, while *Araucaria* and *Acacia* can attain an MAI of up to 20–25 cubic meters per hectare per year. MAI for *Pinus, Picea,* and *Larix* plantations on the best sites in temperate and southern boreal zones can reach 12–15 cubic meters per hectare per year (Webb et al. 1984; Wadsworth 1997; Sagreev et al. 1992). The length of the rotation period for plantations varies from 5–10 to 30 years for major tropical species to 100–200 or more years for major boreal species. Along with the high MAI, the rotation period substantially affects the capacity of plantations to provide carbon sequestration services.

Many plantations do not in practice achieve these high potential growth rates. A number of studies (e.g., Nilsson 1996; McKenzie 1995; White 2003) have concluded that it is seldom possible to achieve high productivity in large-scale plantations, that insufficient forest management results in low survival rates and poor plantation condition, that monocultural plantations increases risks of pest and disease outbreaks, that production costs are often substantially underestimated, that knowledge about plantation growth and yield is poor, and that reliable and operative monitoring systems on plantation condition and dynamics only exist in a few countries. Many of these risks can be overcome where good management practices have been applied.

Plantations have been criticized for their environmental and social impacts—particularly in the tropics, where plantations have replaced natural forests, degrading water and soil resources, and resulting in negative impacts on local and indigenous communities who lose access to lands that formerly supplied them with subsistence resources and livelihoods (e.g., Carrere and Lohmann 1996; Carrere 1999; White 2003). Kanowski (2003) notes that in addition to the suboptimal performance of some plantations, many plantations have been established without appropriate consideration or recognition of trade-offs that were made with other forest services and with the rights and interests of various stakeholders. In Indonesia, for example, the timber plantation program has been a significant driver of natural forest loss, and the establishment of plantations (both for timber and oil palm) was a significant driving force behind the forest and land fires that beset Indonesia during 1997 and 1998 (Barber and Schweithelm 2000). A number of studies have also highlighted the risk of invasive alien species that can escape from plantations (e.g., Richardson 1998; Allen et al. 1997; De Wit et al. 2001).

Development of forest plantations can generate significant social conflicts. For example, in dryland areas plantation species may use more water than the natural vegetation, resulting in less recharge of groundwater and a reduction in streamflow available for other uses (Carrere and Lohmann 1996). Plantations can have social impacts because they employ fewer people than would find jobs on the agricultural land that they may replace and they can increase the price of farmland. They may also influence the viability of agro-enterprises if too many people in an industry sell their land for plantations. Cossalter and Pye-Smith (2003) evaluated such concerns for ''fast wood'' (fast-growing, short rotation species grown for charcoal, pulp, and wood-fiber panel products) plantations, which make up a relatively small but rapidly growing segment of global plantations. They concluded that the impacts of fast-wood plantations depend largely on their management. When poorly planned and executed, fast-wood plantations can cause significant social and environmental problems, but when well planned and executed, they can deliver not just large quantities of wood but a range of other environmental and social benefits.

Similar issues are raised, if not so acutely, by longer-rotation softwood and hardwood plantations. The long-established teak plantations on Java, for example, have been a perennial source of social conflict between local communities and the state forestry corporation that manages them (Peluso 1992). Although fast-wood plantations in the tropics appear to be the type most often responsible for negative environmental and social impacts (Cossalter and Pye-Smith 2003), they are nevertheless also expected to increase the fastest relative to other types of plantations. This is because increasing globalization of the markets for pulp and fiber exerts strong pressure in favor of the lowest-cost producers, based on the interaction of land, labor, and capital costs, combined with productivity. The trend is therefore toward short crop rotations in locations that can provide the highest productivity and the lowest costs (Kanowski 1997).

21.5 Services Provided by Forests and Woodlands

The 1992 U.N. Forest Principles identified the multifunctional and multiservice purpose of the world's forests: ''Forest resources and forest lands shall be managed and used sustainably to fulfill social, economic, ecological, cultural and spiritual needs of present and future generations'' (Forest Principles 1992). The services provided by forests and woodlands are numerous and diverse on all spatial and temporal levels, and include provisioning, regulating, cultural, and supporting services. Some national classifications account for as many as 100 different kinds of forest services, such as delivery of industrial and fuelwood, water protection and regulation, ecotourism, and spiritual and historical values (e.g., Sheingauz and Sapozhnikov 1988; Mather 1999). (See Figure 21.6.) These various forest services relate to each other in many different ways, ranging from synergistic to tolerant, conflicting, and mutually exclusive. The multiservice paradigm of forest management is therefore quite clear in theory but is often very difficult to implement, as it frequently requires difficult choices and trade-offs.

Market approaches can only be used to estimate the value of a few forest services, mostly the ones related to provisioning and that enter formal markets, although markets are also developing for carbon and biodiversity (Scherr et al. 2004). There is no consistent methodology, and usually insufficient information, to estimate credible values for many other forest services. (See Chapter 2.) One recent (and controversial) estimate of the annual value of forest ecosystem services totaled $4.7 trillion, roughly 15% of the global GNP (Costanza et al. 1997). An estimate for the value of Mexico's forests is some $4 billion a year (Abdger et al. 1995). The annual total annual loss to Indian society as a result of forest degradation is estimated at about $12 billion (Joshi and Singh 2003). Ricketts et al. (2004) showed that during 2000–03, pollination services from two forests with a total area of about 150 hectares translated into $60,000 a year for a Costa Rican coffee firm due to increased coffee yield (by 20%) and quality.

Approaches such as these do provide at least an order-of-magnitude insight into the importance of forests for people (Agarwal 1992). Many researchers successfully apply monetary methods to ''nonmarket'' and often ''nontraditional'' services. The concept of total economic value (Pearce 1990; see also Chapter 2) has become one of most widely used frameworks for identifying and categorizing forest benefits (Emerton 2003). TEV aims to account comprehensively for all forest services, estimating direct values (such as timber, fuelwood, NWFPs, grazing and fodder, and recreation), indirect values (including watershed protection, erosion control, macro-climate regulation, and carbon sequestration), option values (considering future economic options in all affected sectors, such as industrial, agricultural, pharmaceutical, and recreational) and existence values (landscape, aesthetic, heritage, cultural, religious, ritual, and so on). In spite of substantial progress in the theory, conceptual basis, and methodology of TEV during the last two decades (Bishop 1999; Lette and de Boo 2002), forest valuation studies often remain a purely academic exercise and rarely have an impact on practical planning and management (Emerton 2003).

The loss and degradation of natural forest as described in the preceding section has been accompanied by a decline in supply of many forest services. These impacts are felt most acutely by rural communities living in or near forests, who suffer a decline in livelihood resources and well-being (Byron and Arnold 1999), although urban dwellers are also affected. For example, based on the comparison of satellite images of 448 U.S. urban areas, over the last 10 years American cities have lost 21% of their forested areas, the damage of which has been estimated to be over $200 billion, although no estimates of the benefits provided by the land use change were calculated (ENN–Reuters 18 September 2003 on American Forests).

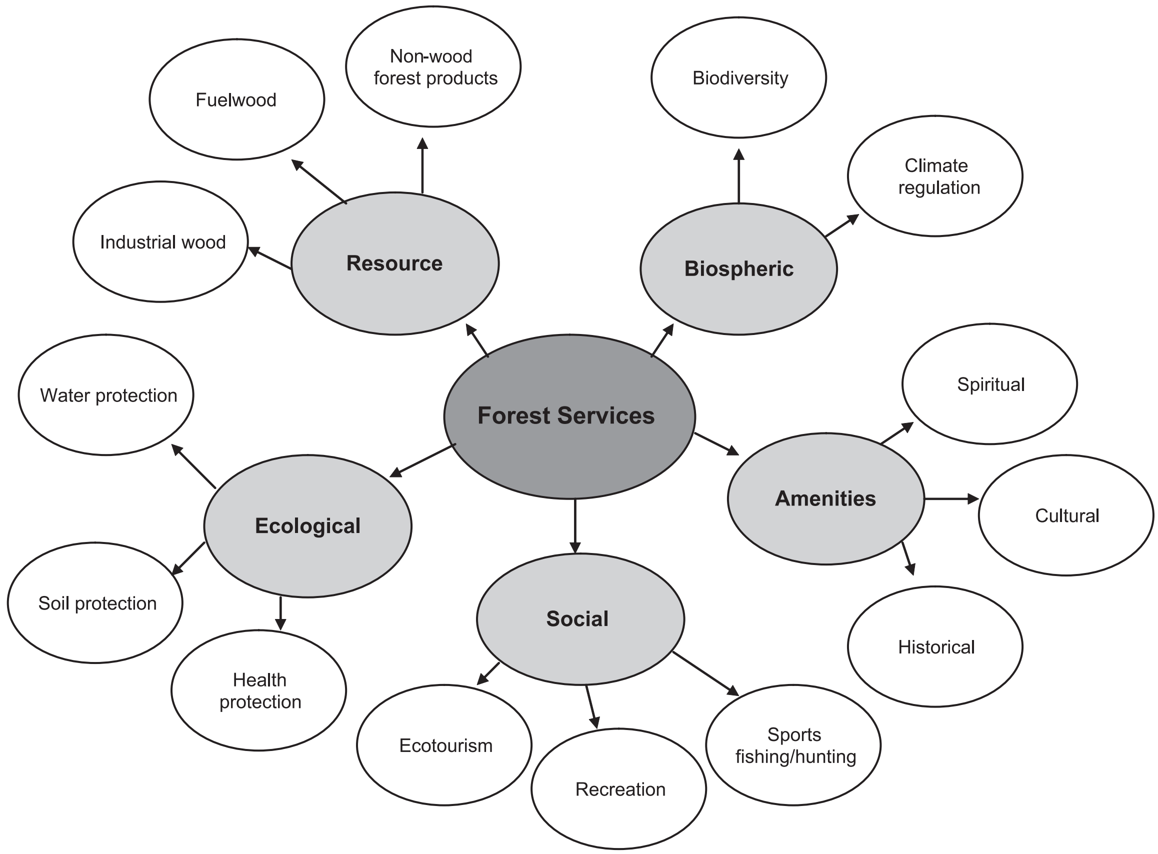


Figure 21.6. Major Classes of Forest Services

21.5.1 Biodiversity

Forests are an important repository of terrestrial biodiversity across three important dimensions: structural diversity (such as areas of forests, natural and protected forests, species mixture, and age structure), compositional diversity (numbers of total floral/faunal species, for example, and endangered species), and functional diversity (the impact of major processes and natural and human-induced disturbances) (Noss 1990; Paumalainen 2001).

Tropical forests cover less than 10% of Earth's land area but harbor between 50% and 90% of Earth's terrestrial species (WRI et al. 1992). The ancient tropical forests of Malaysia, for example, are home to 2,650 tree species, 700 species of birds, 350 species of reptiles, 165 species of amphibians, 300 species of freshwater fish, and millions of invertebrate species (Isik et al. 1997). Other types of forests are not as species-rich as tropical ones but are relatively species-rich ecosystems within their own contexts. Even boreal forests, which harbor only a small number of indigenous tree species (fewer than 100 in Northern Eurasia, for instance) (Atrokhin et al. 1982), have a high diversity at the ecosystem level, and some of their major tree species exhibit high adaptability to extreme climatic conditions. Larch forests, for example, grow at annual average temperature from $+8°$ to $-17°$ Celsius (Sherbakov 1975).

The importance of forest biodiversity for both its existence value as a major component of global biodiversity and its utilitarian value as the source of innumerable biological resources used by people has been recognized by the Convention on Biological Diversity and numerous other bodies and studies (e.g., Heywood et al. 1995; WRI et al. 1992). More recently, studies have shown that biodiversity is also an essential factor in sustaining ecosystem functioning and hence the ecosystem services that forests provide (Naeem et al. 1999). Biodiversity thus provides the underpinning for many of the other forest services discussed in this section. It can also be viewed as a vast storehouse of information from which future services can be derived.

Considerable information on forest-related biodiversity has become available over the past decade (e.g., Heywood 1995; Secretariat of the Convention on Biological Diversity 2001; Groombridge and Jenkins 2002), but consistent global assessments and monitoring are still difficult due to data insufficiency and incompatibility, different standards and definitions, and geographical and thematic gaps in available assessments. Efforts to assess the nature and distribution of biodiversity rely on the selection of particular subsets of species, species assemblages, or environmental features that can be used as surrogates to measure biodiversity as a whole (Margules et al. 2002). A recent global analysis of gaps in protection of biodiversity within the global network of protected areas, for example, used recently completed surveys on the global spatial distribution of over 11,000 species of mammals, amphibians, and threatened bird species as surrogates (Rodrigues et al. 2003).

Forest decline threatens biodiversity at all levels. IUCN estimates that 12.5% of the world's species of plants, 44% of birds, 57% of amphibians, 87% of reptiles, and 75% of mammals are threatened by forest decline (IUCN 1996, 1997). *The World List of Threatened Trees* (Oldfield et al. 1998) indicates that more than 8,000 tree species (9% of the total) are currently threatened with extinction.

It is difficult to say with precision the extent to which forest habitat loss results in population or species extinctions, because our knowledge of forest biodiversity is so incomplete. Nonetheless, it is clear that deforestation, particularly in the tropics, is having extremely negative impacts on biodiversity. Fifteen of the 25 biodiversity "hotspots" originally identified by Myers (1997)—areas with high levels of plant endemism and high levels of habitat loss and threat that between them contain the remaining habitat of 44% of all plant species and 35% of all vertebrate species worldwide—contain tropical forests. These areas once covered nearly 12% of Earth's land surface, but their remaining natural habitat has been reduced to only 1.4% of that surface—that is, 88% of the hotspots' original natural habitat has disappeared. Brooks et al. (2002) concluded that habitat loss in the world's biodiversity hotspots has left extremely large numbers of species threatened, with a high probability of extinction in the absence of immediate conservation action.

Development of protected area systems has been the primary strategy for conserving biodiversity generally (see MA *Policy Responses,* Chapter 5), and significant amounts of forest have come under protected status over the past several decades. (See Box 21.4.) Given the multiple functions of forests, however, and the impracticality of placing enough forests in protected areas to conserve the full range of forest biodiversity substantially, maintenance of the diversity of forest-dependent species in managed forests (such as logging concessions) is also an important strategy (Sayer et al. 1995).

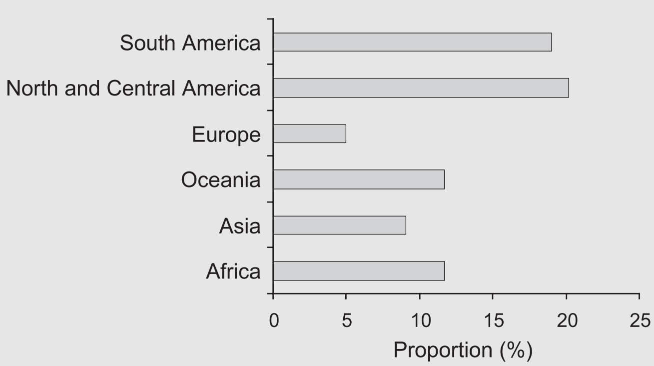
Modification of forest management practices to include biodiversity conservation objectives may not generally require large additional investments, at least in tropical forests (Johns 1997). Some of the simple but important measures that can be taken to this end include retention of small refuge areas and the maintenance of riparian buffer strips at the level of the management unit, and distributing logged and unlogged areas in an appropriate way across the broader landscape. There is also a growing awareness among tropical ecologists that secondary forests recovering from alternative land uses may play an important role in conserving biodiversity (Brown and Lugo 1990; Dunn 2004). It is generally accepted that forest plantations, particularly even-aged and single-species plantations, are less favorable as habitat for a wide range of taxa in different regions of the world (Allen et al. 1997; Davis et al. 2000; Hartley 2002; Humphrey et al. 2002; IUFRO 2003), although there may be some exceptions, such as in degraded landscapes or areas with low original forest cover (Brockie 1992; Kwok and Corlett 2000).

Managing forests to conserve biodiversity (and other non-wood services) requires that a management regime be in place. This is not the case for many countries, particularly developing ones. Eighty-three non-tropical (including all industrial) countries reported that 89% of their forests are managed, although data for developing countries indicate that only 123 million hectares (about 3% of forest area) are managed under formal long-term plans. Regional variation is very high: about 1% of the total forest area in Africa, about 25% in Asia, 85% in Oceania, 55% in North and Central America, and 3% in South America are managed according to such plans. While areas in the tropics seem slightly

BOX 21.4

Forest Protected Areas

A proportion of forests in most countries have protected status. Recent statistics from the UNEP World Conservation Monitoring Centre (UNEP-WCMC 2002) reveal that around 10.4%—470 million hectares—of the world's 4,540 million hectares of forests are under various forms of protection. Countries use a variety of systems for classifying their protected areas. Some have very detailed classifications (up to 20–25 forest protected area categories), although many use some variant of the simpler international IUCN classification system. A CD-ROM published by UNEP-WCMC and the Center for International Forestry Research (Iremonger et al. 1997) contains a detailed analysis of forest protected areas by ecological zone, country, and region. About 7.8% of the world's forests are included in areas that are protected to the level of IUCN categories I-VI.



Percentage of Forest Area in Protected Status by Continent
(FRA 2000)

According to the global map of protected forest areas produced by FAO and UNEP-WCMC as a part of FRA-2000, protected areas cover 479 million hectares—12.4% of the world's forests. Some 15.2% of tropical forests are protected, 11.3% of sub-tropical forests, 16.3% of temperate forests, and 5% of boreal forests. The highest percentage of protected forests is found on the American continent (about 20%) and the lowest in Europe (5%). (See Figure.) These data are not, however, completely consistent (cf., e.g., FFSR 1999; WDPA 2003).

Biodiversity conservation is now widely recognized as the most important objective of protected areas (although many current protected areas were not designed with this in mind), and this objective generates specific size and distribution requirements. Many studies have shown, for example, that conservation of a great deal of biodiversity is not viable in small fragmented areas. Experience in some countries, however, yields examples where even small protected areas can meet some biodiversity conservation objectives (Isaev 1991). This is particularly the case where small protected areas are surrounded by sustainably managed forests. Some countries have established specific categories of protected areas for particular purposes, such as water or soil conservation. TBFRA-2000, for example, reported such designations for soil protected in most industrial countries such as Russia (90.8 million hectares), Kazakhstan (9.3 million hectares) and Greece (2.5 million hectares).

Formal designation of protected areas, however, does not guarantee their effective management. In many developing countries, protected areas often exist on paper but lack active management and are in fact subject to illegal logging and wildlife poaching, agricultural encroachment, and settlement. In some cases they may be completely or partially treeless. As a result, experts and policy-makers frequently debate how best to divide limited financial and technical resources between designating new protected areas, strengthening management of existing protected areas, and establishing novel forms of community-based conservation—working with local and indigenous communities outside of formal state-run protected areas (Barber et al. 2004).

underestimated, the data for some large non-tropical forest countries should be used with caution due to different national definitions of ''managed forests'' (FAO 2001c; Shvidenko 2003).

21.5.2 Soil and Water Protection

The global condition of the world's soils and hydrological systems is not well known, but it is considered to be far from satisfactory. (See Chapters 7, 20, and 22.) From 1945 to 1990, a vast area (1.2 billion hectares) of land is estimated to have suffered moderate to extreme soil degradation, and degraded areas accounted for 17% of Earth's vegetated lands (Oldeman et al. 1990; WRI 1992). The major causes for this extensive degradation are a number of current practices in agriculture, forest management, and grazing.

In many regions, forest is a major stabilizing component of natural landscapes, providing protection of soil and water, households, and fields and reducing or preventing floods and landslides. In the Ukraine, for example, soils on 11% of the territory are in good condition, 18% satisfactory, 22% in conflict, 25% pre-critical, and 24% in critical ecological condition. The relative conditions in different areas are strongly correlated with the extent of forest cover, which varies from 26% to 3% across the country (Yukhnovsky 2003). Levels of soil erosion in the tropics may be 10–20 times higher on areas cleared of forests, due to construction of roads, skidder tracks, and log landings during mechanical logging, than in undisturbed natural forests, and this is particularly the case in mountainous and other areas characterized by fragile soils (Wiersum 1984; Dickinson 1990; Baharuddin and Rahim 1994; Douglas 1996; Chomitz and Kumari 1998).

Regulation of hydrological cycles and processes is one of the important services provided by forests at large scales. Globally, forests' hydrological functions have been claimed to include increasing precipitation and decreasing evaporation; regulating the total and redistribution of surface and belowground runoff; smoothing out the seasonal course of river discharges; increasing total annual river runoff; protecting landscapes against soil erosion and landslides, in particular in mountains; preventing and mitigating the consequences of floods; maintaining water quality; protecting river banks against destruction (abrasion); and preventing siltation of reservoirs (e.g., Protopopov 1975, 1979; Rakhmanov 1984; Rubtsov 1990; Pielke et al. 1998; Bruijnzel 2004).

While forests play an undeniably important hydrological role across the globe, the specifics of this role vary substantially among biomes, landscapes, and forest types. Differences between tropical, temperate, and boreal zones, for example, can be great (e.g., Hamilton and King 1983; Bruijnzeel 1989; Versfeld et al. 1994; Sandström 1995). Research in tropical forest areas indicates that the roles of forests in watershed hydrology may have been overestimated in some cases: in arid areas, for example, trees evaporate more water than other vegetation types, and there is little evidence that forests attract precipitation (with the exception of cloud forests); forests reduce runoff but are not always effective at flood prevention, since tropical forest soils become rapidly saturated in tropical rainstorms. Some studies do conclude, however, that forests promote an even seasonal and annual flow, particularly in the dry season (Hamilton and King 1983; Dhawan 1993; Cossalter and Pye 2003; Kaimowitz 2004).

Because of the important role that forests play in protecting watersheds, many countries grant protected status to forests that serve this purpose. Such forests often include protective belts along rivers, lakes, artificial water reservoirs, and other bodies of water, and forests on steep slopes (Dudley and Stolton 2003; DePhilip 2003).

Many of the world's major rivers begin in mountain highlands, and more than half the planet relies on fresh water flowing from these areas. (See Chapter 24.) One third of the world's 105 largest cities obtain their water supply from forested watersheds. However, 42% of the world's main river basins have lost more than 75% of their original forest cover, and there is a clear relationship between population density and forest loss in the river basin (Revenga et al. 1998). The Yangtze watershed in China (home to some 400 million people) has lost 85% of its original forest cover, and in 1998 severe flooding along the Yangtze killed more than 3,800 people and caused over $20 billion in damage (Eckholm 1998). Many countries in the arid zone face an acute water deficit. In South Africa, for example, 54% of available runoff is currently used, and the level of use is expected to increase by 75% during the next 25 years. Twenty-eight countries experienced shortages of fresh water in 1998, and this number is expected to increase to 56 countries by 2026 (Versfeld et al. 1994; Sandström 1995).

Water and soil protection services of forests depend critically on the area and spatial distribution of forests over landscapes. It has been suggested that in the temperate zone, the minimal forest coverage that provides significant protection of landscapes over large territories varies from 7% to 30%, depending on region, climate, vegetation type, specific landscape features, and other factors (Protopopov 1975; Shvidenko at al. 1987). In semiarid and arid conditions, under a system of protective tree shelterbelts and trees outside of forest over the area to be protected, significant levels of protection for water and soil services can be attained with forest cover of 3.5% to 5–6%, as in the steppe zone of Ukraine and Russia, for example (Pilipenko et al. 1998).

21.5.3 Protection of Fragile Ecosystems: Forests in Mountains, Drylands, and Small Islands

Forests play a specific and very important environmental and social role in fragile ecosystems and landscapes, such as mountains, drylands, and small island ecosystems, particularly at the local level. People in these areas often have a high dependence on forest services. (See Chapters 22, 23, and 24.)

Forests in mountains have local and regional value as regulators of water supplies, centers of biological diversity, providers of forest products, and stabilizers of land against erosion. Due to the generally greater precipitation in mountains and the high ability of montane (in particular cloud) forests to capture atmospheric water, mountains play an extremely important role in maintenance of hydrological cycles affecting large territories. The alpine catchment of the Rhine River, for example, occupies only 11% of the river basin but supplies 31% of the annual flow and more than 50% of the summer flow (Price 1998). In semiarid and arid areas, over 90% of river flow comes from the mountains.

Trees and forests in dryland areas provide fuelwood, small roundwood (poles for building houses and fences), non-wood forest products (foods, medicinal products, bushmeat, fodder, and so on), and diverse regulating and cultural services. Their most critical functions in many dryland areas are soil conservation, shade, and shelter against wind.

The forest cover of 52 small island states and territories is insignificant in global terms—only 0.2% of global forest area in 1995 (FAO 2003b). But forests and trees on these islands are extremely important for the well-being of the local populations, the conservation of biological diversity, and the maintenance of environmental conditions both on land and in surrounding marine ecosystems. (See Chapter 23.) They play an important role in protecting watersheds, maintaining water supply, and protecting the marine environment.

Mangroves and other tidal forests are highly productive ecosystems that are important feeding, breeding, and nursery backgrounds for numerous commercial fish and shellfish, including most commercial tropical shrimp. (See Chapter 19.) FAO (2003b) has reported decreases in the extent of mangrove forest from 1980 to 2000 at an annual rate exceeding 1%.

Forests on small islands are extremely important for coastal protection against the strong winds, high rainfall, and storm surges of cyclones and hurricanes, and they serve as sediment traps for upland runoff sediments (Roennbaek 1999). Biodiversity conservation is another crucial service provided by forests on small islands. High endemism is an intrinsic feature of small island biodiversity: about 30% of higher plant species, 20–25% of birds, and 25–50% of mammals are island endemics (WRI et al. 1996).

21.5.4 Fiber, Fuel, and Non-wood Forest Products

Wood is currently the most economically important forest product. During 1996–2000, about 3.3 billion cubic meters of wood were harvested annually from the world's forests, and roundwood production has steadily increased by approximately 0.8% per year (FAO 2002a). By region, the largest annual increases during this time were observed in Europe (4.8%) and Oceania (3.5%). Only Asia experienced a substantial decrease in harvested wood (–1.2% per year), which is explained by dramatic decreases in three countries: Malaysia (–33%), Indonesia (–16%, due to economic and political disturbances during this period), and China (–8%, due to the drastic national measures taken in 1998 to restrict harvesting). A significant proportion of harvested wood and wood products is traded internationally. For a detailed assessment of wood production, see Chapter 9.

In the temperate and boreal zone, 63% of forests are classified as available for wood supply. The average growing stock of forest available for wood supply is between 105 and 145 cubic meters per hectare, with considerable variation among countries (from less than 50 to over 250 cubic meters for some European countries with strong silvicultural traditions). On average, the growing stock of forest available for wood supply increased by about 640 million cubic meters a year during the last decade, mostly in Europe and North America, due to forest management and global change (in particular, a longer growing period in the boreal zone, increased temperature and precipitation, elevation of the atmospheric concentration of CO_2, and increasing nutrient deposition) (e.g., Myneni et al. 2001; Ciais et al. 2004).

Removal as a percentage of mean annual increment is an indicator of sustainability of wood supply. For the temperate and boreal region as a whole, this figure is estimated to be 52.6%, with strong regional variations between North America (78.6%), Europe (59%), and the former Soviet Union (16.8%). Conifers are used more intensively (62.5%) than broadleaf forests (42.2%). Annual felling in the temperate and boreal domain (1,632 million cubic meters, of which over half is in the United States and Canada and 28% in Europe) is, however, substantially higher than the level of removals (1,260 million cubic meters)—implying a high level of harvest loss (FAO 2002a).

The total area under timber harvesting schemes in 43 selected countries accounting for approximately 90% of the world's tropical forests is estimated to be about 50 million hectares (55% in tropical forests of Asia and Oceania, 33% in Latin America, and 12% in Africa). Annually harvested area is estimated to be about 11 million hectares (29% in Africa, 54% in Asia and Oceania, and 17% in Latin America), although harvesting intensity is highly variable by country, ranging from 1 to 34 cubic meters per hectare (FAO 2001c).

Accessibility of forests is also an important factor for assessing the sustainability of wood supply. Approximately 51% of the world's forests are within 10 kilometers of major transportation infrastructure, including big rivers (from 38% in South America to 65% in Africa), and 78% are within 50 kilometers. Boreal and tropical forests are more remote than others. Some 14% of the world's forests were considered unavailable for wood supply, as they are located either in protected areas (12.4%) or in inaccessible mountain areas (FAO 2001c).

The importance of plantations as a source of timber is likely to continue to increase. For example, it is expected that forest plantations in China (currently about 47 million hectares) will provide up to 150 million cubic meters of wood annually (Jiang and Zhang 2003).

Fuelwood meets about 7% of energy demand worldwide, including about 15% in developing countries and 2% in industrial countries (WEC 1999). Globally, about 1.8 billion cubic meters of wood is used annually for fuel (including charcoal production). However, there is a large amount of variation in these figures, and more than 70% of energy needs in 34 developing countries and more than 90% in 13 countries (of which 11 are in Africa) are met through fuelwood. Woodfuel constitutes about 80% of total wood use in developing countries, where about one third of the total forest plantations were established primarily for that purpose. More than 60% of these plantations are in Asia and 25% are in Latin America. Plantations currently supply 5% of woodfuel, although it is estimated that woodfuel supply from plantations will grow 3.5-fold by 2020 (FAO 2001c).

Estimates of the potential of the world's forests to meet most of the world's demand for fibers and fuel in the future vary considerably and are significantly affected by economic accessibility and protection status of forests. Hagler (1995) estimated that only 2.1 billion hectares of forest are usable for fiber and fuel and that this forest area can sustain a long-term harvest of 3.7 billion cubic meters of wood per year. This study did not, however, consider current and potential wood supply from trees outside forests. Nilsson (1996) estimated that by 2020 the world demand for industrial roundwood and fuelwood (including charcoal) will be 2.4 billion and 4.25 billion cubic meters, respectively. However, a forecast by Broadhead et al. (2001) for fuelwood is only about 1.9 billion cubic meters for the same year (including charcoal).

According to these analyses, the world's forests are very close to exhausting their fiber and fuel potentials, and intensive measures will be needed to satisfy the deficit projected for 2020. Nilsson (1996) argues that even if the high forecasts are accurate, the deficit will not occur in reality due to market mechanisms, which are likely to achieve equilibrium between supply and demand. Broadhead et al. (2001) argue that fuelwood demand has in fact already peaked. More detailed information on this issue may be found in Chapter 9, where considerable evidence is presented in support of the conclusion that a global shortage of wood, per se, is not likely to occur in the near future, although there are likely to be significant regional disparities, such as unsatisfied market demand for large-dimension timber of high quality. Overall, land use changes and policy decisions will likely have a greater impact on forest ecosystems than timber harvest.

No doubt, wood has a great future. As construction material (25% of the annual global wood harvest), wood outperforms steel and concrete on an environmental basis (CWC 1999). Wood is a renewable resource and can also be recycled or reused. Development of new wood-processing technologies and products, environmental scrutiny, new applications, and new markets are some of trends that are expected to influence wood supply and demand over the next few decades (Roche et al. 2003; Pisarenko and Strakhov 2004), and rapid urban growth in developing countries has substantially increased the demand for industrial wood and fuel (Scherr et al. 2002).

Non-wood forest products (defined as goods of biological origin other than wood, derived from forests, other wooded land, and trees outside the forests) (FAO 1999b) include a tremendous diversity of items—some of which enter formal markets, but many that do not (FAO 2001b, 2001c, 2001f; UNECE 1998). They can be classified in a number of broad categories according to their end use: edible products; fodder for domestic animals; medicines; perfumes and cosmetics; colorants; ornamentals; utensils, handicrafts, and construction materials; and exudates like gums, resins, and latex. Overall, they play an important role in the daily life and well-being of hundreds of millions of people worldwide as well as in the national economies of many countries.

At least 150 NWFPs are of major significance in international trade, and the annual export value of these products was estimated at $11 billion in 1994. China is the leading exporter of NWFPs, followed by India, Indonesia, Viet Nam, Malaysia, the Philippines, and Thailand (Iqbal 1995). NWFPs provide subsistence, employment, and income, particularly for the rural poor, and support small, household-based enterprises, especially in developing countries (e.g., Arnold 1998; Ciesla 1998). The most reliable estimates indicate that from 200 million to 300 million people earn much of their subsistence income from nonindustrial forest products (Byron 1997). From 150 million to 200 million people belonging to indigenous groups in over 70 countries, mostly in tropics, depend on NWFPs to sustain their way of life, including their culture and religious traditions (CIDA 1998).

Edible NWFPs—vegetables, fruits, nuts, seeds, roots, mushrooms, spices, bushmeat, bee products, insects, eggs, nests, and so on—are particularly important in tropical and sub-tropical regions. For example, bushmeat and fish provide more than 20% of the protein in 62 least developed countries (Bennet and Robinson 2000). And in rural areas of many countries, a significant relationship exists between food security and the degree of contribution of NWFPs to households (Odebode 2003). From 8% to 46% of indigenous tree species serve as a source for food and fodder in the Pacific region (Siwatibau 2003).

Many edible products are increasingly exported, including honey and beeswax from Africa, bamboo from China (1.6 million tons of fresh shoots exported in 1999), and wild edible mushrooms, mostly morel mushrooms (a trade with a total annual value of $50–60 million). In the mid-1990s, the cost of importing of edible NWFPs to three main markets—Europe, the United States, and Japan—was estimated at about $2.5 billion (Iqbal 1995).

Fodder is of great importance in many regions, particularly in the arid and semiarid zones and in animal-based production systems. In many developing countries, 30–40% of domestic animals depend on forests for grazing and fodder (FAO 2001c).

About three quarters of the people in developing countries use traditional medicines, and the ratio of traditional healers to western-trained doctors reaches 150:1 in some African countries (FAO 2001c). Medicinal plant species (mostly from the forest) used by local populations and as trade products number in the thousands, and some 4,000 commercially important medicinal plant species are used in Southeast Asia alone. The value of the world trade in medicinal plants in 1992 was on the order of $171 million (Iqbal 1995). Medicinal plant exports are economically important for some countries, such as Morocco and Egypt, which export from 7,000 to 15,000 tons of medicinal plants annually (Lange and Mladenova 1997).

Forest plants are also widely used in the development of modern medicines for heart disease, cancers, leukemia, and HIV/AIDS. According to one survey, 90% of the most-prescribed pharmaceuticals in the United States contain compounds of forest origin (Lyke 1995). This is particularly remarkable in light of the fact that only 5–15% of higher plant species have been investigated for the presence of bioactive compounds (ten Kate and Laird 1999).

Rattan is the most important internationally traded NWFP. There are more than 600 species of rattan, some 10% of which are commercially used. Bamboo (more than 500 species) is the most commonly used NWFP in Asia, where about 20 million tons are produced annually. (See Chapter 9.) The average annual value of the world trade in bamboo ware is on the order of $36 million (FAO 2001c).

Global estimates of the total monetary value of NWFPs are very approximate and express an order of magnitude rather than documented market prices, particularly for subsistence uses. A number of studies (Myers 1997; UN-CSD/IPF-CSD 1996; Michie et al. 1999) have attempted to estimate the value of the subsistence use of NWFPs, arriving at figures ranging from $90 billion to $120–150 billion. This aggregate figure includes valuation of fodder and grazing ($40–50 billion); edible products ($20–25 billion); traditional medicines derived from plants, insects, and animals ($35–40 billion); and non-wood construction materials, such as thatch grass and bamboo, and other similar items ($25–35 billion).

21.5.5 Carbon Sequestration

Forests play an important role in the global carbon cycle and consequently in regulating the global climate system. Two main features of forests define this role. First, the world's forests accumulate a major part of the planet's terrestrial ecosystem carbon. Second, forests and wetlands are the two major land cover classes that are able to provide long-term sequestration of carbon. Accumulation of carbon in wood and soils results in a more significant share of total net primary productivity being stored in the long term than in other land cover classes and can represent as much as 10–15% of NPP (Field and Raupach 2004; Shvidenko and Nilsson 2003).

Estimates for the carbon stock in the world's forest ecosystems vary in the range of 352–536 billion tons of carbon (Dixon et al. 1994; Houghton 1996; Brown 1998; Saugier et al. 2001). The IPCC estimate of carbon content for three major forest biomes (covering 4.17 billion hectares) is 337 billion tons in vegetation and 787 billion tons in the top 1 meter layer of soils (IPCC 2001a). FRA-2000 estimated the aboveground tree biomass at 422 billion tons of dry matter (or 5.45 kilograms of carbon per square meter). The estimate by Kauppi (2003), based on FRA-2000, is 300 billion tons of carbon for tree biomass of forest ecosystems. Previously reported estimates—8.6 kilograms carbon per square meter by Dixon et al. (1994), 10.6 kilograms by Houghton (1999), and 6.6 kilograms by Kauppi (2003)—significantly overestimated densities. Based on analysis of all available sources and taking into account the above analysis of global forest area, it is estimated here that the total biomass of forest ecosystems is likely to include 335–365 billion tons of carbon (a priori confidence interval 0.9).

Forest carbon stocks and fluxes, and the major drivers of their dynamics, have been quantified for certain globally important forest areas (Zhang and Justice 2001; Houghton et al. 2001b; Fung et al. 2001; DeFries et al. 2002; Dong et al. 2003; Birdsey and Lewis 2003; Baker et al. 2004). Four major processes define whether forests serve as a net carbon sink or source: net primary productivity, decomposition (heterotrophic respiration), natural and human-induced disturbances (including harvest and consumption of forest products), and transport of carbon to the lithosphere and hydrosphere. The rate of accumulation of carbon over a whole ecosystem and over a whole season (or other period of time) is known as the net ecosystem productivity. In a given ecosystem, NEP is positive in most years and carbon accumulates, even if only slowly. However, major disturbances such as fires or extreme events that cause the death of many components of the biota release greater-than-usual amounts of carbon. The average accumulation of carbon over large areas or long time periods is called net biome productivity.

Productivity of forests varies significantly by continents, ecological zones, and countries, and no consistent global inventory of forest net primary productivity exists. Current estimates are based on potential (but not actual) forest cover and do not adequately take disturbances into account. This results in overestimation of biomass by 40–50% and overestimates of NPP by 25–35% for some large regions of the planet (Haberl 1997; Shvidenko et al. 2001).

Based on current understanding of the terrestrial vegetation global carbon cycle, NPP is estimated at 60 billion tons of carbon per year (e.g., Melillo et al. 1993; Goldweijk et al. 1994; Alexandrov et al. 1999), decomposition at 50 teragrams of carbon per year, net ecosystem productivity at 10 billion tons of carbon per year, and net biome productivity at 1 billion tons of carbon per year (0.7 ± 1.0 billion tons during 1988–99). The proportion of global NPP provided by forests is different in different climate zones and remains rather uncertain. Factors that influence the net uptake of carbon by forests include the direct effects of land use and land cover change (such as deforestation and regrowth), harvest and forest management, and the response of forest ecosystems to CO_2 fertilization, nutrient deposition, climatic variation, and disturbances.

Deforestation in the tropics has the greatest impact on the carbon cycle of any land use and land cover change. It is reported that land use change (mostly deforestation) is the source of 1.6 ± 0.8 billion tons of carbon per year (Houghton et al. 1999, 2001), although other estimates of net mean annual carbon fluxes from tropical deforestation and regrowth were 0.6 (0.3–0.8) and 0.9 (0.5–1.4) billion tons for the 1980s and 1990s (DeFries et al. 2002). Dixon et al. (1994) estimated that global forests were a net source of 0.9 ± 0.4 billion tons of carbon in the 1990s, including large sources in the low-latitude forests (1.6 ± 0.4 billion tons a year) and net sinks in mid-latitude (0.26 ± 0.09 billion tons a year) and high-latitude (0.48 ± 0.1 billion tons a year) forests.

Inversion studies using atmospheric-transport models indicate that land in the temperate and boreal latitudes of the Northern Hemisphere was a sink for 0.6–2.7 billion tons of carbon a year during the mid-1980s to mid-1990s, although patterns of spatial distribution of this sink are rather contradictive (Fan et al. 1998; Bousquet et al. 2000; Rayner et al. 1999; Battle et al. 2000; Prentice et al. 2001), and there is substantial interannual variation of forest NBP, which can reach three- to fivefold for large regions. Goodale et al. (2002) estimated that northern forests and woodlands provided a total sink for 0.6–0.7 billion tons of carbon a year during the early 1990s, consisting of 0.21 tons in living biomass, 0.08 tons in forest product, 0.15 tons in dead wood, and 0.13 tons in soil organic matter.

Russian forests, which account for about two thirds of total boreal forests, experienced severe disturbances during this period, which resulted in an estimated annual carbon sink for 1988–92 of 0.11 billion tons of carbon (Goodale et al. 2002). Later it has been shown that the forest sink in Russia during this period was minimal over the last four decades: the annual average NBP of Russian forests has been estimated at 0.43 billion tons of carbon per year from 1961 to 1998 (Shvidenko and Nilsson 2003). Canadian forests served as a net carbon sink before the 1980s but became a carbon source as the result of increased disturbances and changes in the age class distribution (Kurz and Apps 1999).

Recently disturbed and regenerated forests usually lose carbon from both soil and remnant vegetation, whereas mature undisturbed forests maintain an overall neutral carbon balance (Apps et al. 2000). The rate of carbon sequestration depends upon age, site quality, species composition, and the style of forest management. Mature and over-mature boreal forests in many cases actually serve as a net carbon sink (Schulze et al. 1999), which probably relates to accumulation of carbon in forest soils and uneven-aged forest structure.

The post-Kyoto international negotiation process envisages an important role for forests in current and future efforts to mitigate climate change. Forest management operations that simultaneously improve the condition and productivity of forests and stabilize natural landscapes are able to increase the carbon stock of forest ecosystems and ensure its persistence. These activities include afforestation and reforestation, thinning, improving forest protection, increasing efficiency of wood processing, and use of wood for bioenergy. Numerous studies show significant potential of the world's forests in this respect. Implementation of special carbon management programs in Russia, for example, allows for sequestration of 200–600 teragrams of carbon annually during the next 100 years in a globally competitive carbon market (Shvidenko et al. 2003). The ability of forests to sequester carbon effectively takes on special significance since the Kyoto Protocol entered into force in 2005. Implementation of successful carbon management will require improvements in national forest policies, legal instruments, monitoring and reporting in many countries, and general progress in the transition of world forestry to sustainable forest management.

Plantations are also increasingly established as a response to climate change. A number of countries already have programs to establish forest plantations for carbon sequestration. In Costa Rica, for example, reforested conservation areas are credited with income for the carbon sink and watershed protection services they provide (Chichilnisky and Heal 1998). By 2000, about 4 million hectares of plantations worldwide were established with funding for carbon sequestration. However, despite much progress in the post-Kyoto Protocol international negotiation process, some important political and economic questions concerning the use of forestry and land use change for mitigating climate change remain to be resolved. The protocol allows carbon sequestered by afforestation or reforestation after 1990 to be counted as an offset for emissions under certain circumstances. Some observers (e.g., Schulze et al. 2002) fear that this might offer incentives to fell older, natural woodland (for which no offsets are available) and replace them with plantations. However, the accounting and verification procedures, such as those agreed in the Marrakesh Accords to the protocol, are designed to eliminate such perverse incentives.

21.5.6 Sociocultural Values and Services

Forests are highly valued for a host of social, cultural, and spiritual reasons. Forests and people have co-developed, with people shaping the physical nature of most forests (including those we today consider "natural") and the forest, in turn, exerting a powerful influence over human cultures and spiritual beliefs (Laird 1999; Posey 1993; UNESCO 1996). For many indigenous and traditional societies, forests are sacred and sometimes supernatural places, linked to both religious beliefs and the very identity of some communities and peoples (Parkinson 1999). The widespread existence of "sacred groves" in many societies is a physical manifestation of this spiritual role and has contributed to forest conservation. (See Chapter 17.)

Forests provide spiritual and recreational services to millions of people through forest-related tourism. Nature-based tourism has increased more rapidly than the general tourism market, evolving from a niche market to a mainstream element of global tourism, with annual growth rates estimated to be in the range of 10–30%. (See Chapter 17.) Although it is difficult to estimate with any precision what proportion of regular tourism has been redefined as "nature-based" or how many "nature-based tourists" are drawn to destinations because they are forested, it is nevertheless evident that forests, woodlands, and the species they support are a significant element of many ecotourism destinations—from the national parks of North America to the megafauna-rich savannas of Africa.

21.5.7 Services Provided by Agroforestry Systems

Although forests and woodlands can be a substantial component of agroforestry systems, trees outside forests are also a crucial component of these systems. Services provided by agroforestry systems vary between different climate regions and include woody and non-woody forest products for commercial and subsistence use; maintenance of soil fertility via organic matter input to the soil, nitrogen fixation, and nutrient recycling (Szott and Palm 1996; Buresh and Tian 1998); reduction of water and wind erosion (Beer et al. 1998; Yukhnovsky 2003); conservation of water via greater infiltration (Bharati et al. 2002); enhanced carbon capture (Lopez et al. 1999); and maintenance and management of biodiversity in agricultural landscapes (Beer et al. 2003).

21.5.8 Discussion

While it is clear that the value of forest services is very high, there are many gaps in scientific understanding and few practical solutions to reconciling the conflicts that arise from the competing values that different user groups ascribe to different forest services. Interests of landowners, local communities, governments, and the private sector vary and frequently conflict in both spatial and temporal terms. The time horizon for using individual forest services is substantially different, for example, for forest-dependent indigenous communities and large logging companies.

There are many similarities in the importance and use of forest services in industrial and developing countries, as well as clear geographical, national, and user group differences. For example, the relative importance of wood production has been ranked as "high" and "medium" by 78% and 89% of respondents in United States and France, respectively, but estimates for grazing were 33% and 4%, and for nature protection 50% and 100% (Agarwal 1992).

Expert estimates presented in Tables 21.5 and 21.6 indicate, to some extent, current understanding of the relative importance of different forest services for tropical and non-tropical forests. Although it is not easy to predict future trajectories of changes for these estimates, demands on forests as sources of both fiber and other services will undoubtedly grow significantly. Two central factors of global change, however, will likely be determinative: the extent to which development challenges are met and poverty is reduced in many parts of the world (IIASA and FAO 2002) and the extent to which the direct and indirect impacts of climate change on the capacity of forests to provide services might exceed the resilience of forest ecosystems in many regions.

21.6 Drivers of Change in Forest Ecosystems

Understanding the drivers of change in forest condition at different spatial and temporal scales is a complicated task. As a rule, such changes are the result of interactions among many factors—social, ecological, economic, climatic, and biophysical. (See Chapter 3.) Rapid population growth, political instability, market forces, institutional strengths or weaknesses, natural and human-induced disturbances, and many other factors may be important. Biophysical factors, such as a region's history of landscape transformation (Mertens and Lambin 2000), the high sensitivity of forest soils to machinery used for logging (Protopopov 1979), or the high flammability of boreal forests (Kasischke and Stocks 2000) can also play a significant role (McConnell 2004).

21.6.1 Tropical Forest Ecosystems

Forest degradation and conversion to other land uses are the two main processes of change occurring in natural tropical forest ecosystems. Numerous studies have attempted to ascertain the direct and indirect drivers of tropical deforestation and the relationships among them, and broadly conclude that in many situations it is impossible to isolate a single cause due to the complex socioeconomic processes involved, and the diverse circumstances in which it occurs, which often obscures underlying patterns (Walker 1987; Roper 1996). Despite this complexity, it is clear that tropical deforestation is caused by a combination of direct and indirect drivers, that these drivers interact with each other, often synergistically, and that the specific combinations of drivers vary between regions of the globe, countries, and even between localities within countries.

The assessment of tropical deforestation provided by Geist and Lambin (2001, 2002) and further elaborated in Lambin et al. (2003) is presented here. It provides a comprehensive review and synthesis of recent literature and draws on analysis of 152 subnational case studies.

21.6.1.1 Direct Drivers

Direct drivers of tropical deforestation are human activities or immediate action at the local level, such as agricultural expansion, that originate from intended land use and directly affect forest cover (Geist and Lambin 2002). These direct drivers can be broadly categorized into those related to agricultural expansion, wood extraction, and infrastructure extension.

Agricultural expansion includes shifting cultivation (both traditional swidden agriculture and the more destructive "slash-and burn" cultivation); permanent agriculture, which may be at large or small scales and, in the latter case, for either commercial or subsistence purposes; pasture creation for cattle ranching; and sponsored resettlement programs with the objective of converting forest to agriculture, estate crops, or timber plantations.

Wood extraction includes commercial wood extraction (state-managed or private logging concessions), fuelwood extraction and charcoal production for both domestic and industrial uses, and polewood extraction for both domestic and urban uses. Most timber extraction in tropical regions is done without effective management, and logging often inflicts a great deal of damage on the remaining forest stand (Verissimo et al. 2002; Schneider et al. 2002), although technologies of reduced impact logging have been successful on an experimental scale (Sist et al. 1998; Ceder-

Table 21.5. Major Services Provided by Tropical Forests and Woodlands to Various User Groups (Based on regional expert estimates)

User Group	Freshwater Yield	Fuel	Timber and Pulp	NWFP	Biodiversity	Amenities	Carbon Storage
Local communities	5	5	3	4	2	4	2
Loggers	2	4	5	2	1	2	2
Downstream users							
Cities	4	3	4	3	2	4	2
Agriculture	5	4	3	4	3	3	1
Industry	3	2	5	1	0	1	1
Timber traders	1	3	5	3	0	0	1
National	5	4	4	3	4	4	3
Global	3	4	3	4	5	3	3

Key:
5 – crucial 2 – moderately important
4 – very important 1 – sporadic use
3 – important 0 – not used

Table 21.6. Major Services Provided by Temperate Forests and Woodlands to Various User Groups (Based on regional expert estimates)

User Group	Freshwater Yield	Fuel	Timber and Pulp	NWFP	Biodiversity	Amenities	Carbon Storage
Local communities	5	5	3	4	2	4	2
Loggers	2	4	5	2	1	2	2
Downstream users							
Cities	4	3	4	3	2	4	2
Agriculture	5	4	3	4	3	3	1
Industry	3	2	5	1	0	1	1
Timber traders	1	3	5	3	0	0	1
National	5	4	4	3	4	4	3
Global	3	4	3	4	5	3	3

Key:
5 – crucial 2 – moderately important
4 – very important 1 – sporadic use
3 – important 0 – not used

gen 1996; Mårn and Jonkers 1981; Applegate et al. 2004) (See also MA *Policy Responses,* Chapter 8.) Illegal logging is also a major concern in many tropical countries. (See Chapter 9.) Illegal logging drives harvesting above planned legal limits, thereby impairing efforts at sustainable forest management, and is a powerful element of organized crime (e.g., Curry et al. 2001; Tacconi et al. 2003). According to assessments by international institutions such as the World Bank and WWF, about 70 countries have substantial problems with illegal logging, leading to annual losses of government income exceeding $5 billion and total economic losses of about $10 billion (Pisarenko and Strakhov 2004).

Infrastructure extension includes transport infrastructure (roads, railroads, and rivers); market infrastructure (such as sawmills and food markets); settlement expansion; and a variety of resource extraction, energy, and industrial infrastructure (such as hydropower, oil exploration, mining, and electrical grids).

Agricultural expansion is by far the most important direct driver of deforestation (in as much as 96% of cases studied) (Geist and Lambin 2002), and higher prices for agricultural products are a key indirect driver (Angelsen and Kaimowitz 1999). There is considerable regional variation in the kinds of agricultural expansion affecting tropical forests. Slash-and-burn clearing in Asia, for example, is more prevalent in uplands and foothills, whereas in Latin America, it is mainly limited to lowland areas. Pasture creation for cattle ranching is a major direct driver of forest loss in mainland South America, but much less so in other regions.

Similar regional variation exists for commercial wood extraction, which was a factor in 67% of cases studied, but varied from being a direct driver of deforestation in 78% of Asian cases to 40% of Latin American cases and 26% of African cases. This is not surprising, since significant industrial logging for the international tropical timber trade now occurs only in seven Asian countries (Indonesia, Malaysia, Myanmar, Cambodia, Laos, Papua New Guinea, and the Solomon Islands), although many other countries have commercial logging operations for domestic and international markets (FAO 2002a). In some cases, large timber corporations have taken advantage of weaker or more corrupt governments (Forests Monitor 2001), which have ceded large tracts of forests to logging firms—for instance, 75% of Cameroon's forest area (WRI 2000b) and 50% of the forest area of Gabon (WRI 2000a).

By contrast to the relative importance of commercial logging in Asia, fuelwood gathering for domestic use was found to be a direct driver in 53% of African cases but only 33% of Asian and 18% of Latin American cases.

Infrastructure expansion was found to be a direct driver in 72% of cases overall, varying from 47% in Africa to 66% in Asia and 83% in Latin America. In particular, road extension was found to be one of the main specific direct drivers of tropical deforestation, especially in Latin America. The extension of roads, rail, and water transport now leaves 65% of forests in Africa 10 kilometers or less from a transportation line (FAO 2001c). By contrast, the development of private enterprise infrastructure (dams, mines, oil exploration) appears to be a minor direct driver of tropical deforestation globally, although it is important in some regions (such as hydropower development in Southeast Asia and oil development in the Peruvian, Ecuadorian, and Colombian Amazonian lowlands).

Tropical deforestation can rarely be explained by a single direct driver. In the Geist and Lambin assessment, single direct drivers only explained 6% of the cases. In particular, agricultural expansion in tandem with infrastructure development and/or logging are the most frequent combinations of direct drivers (''tandems'') causing deforestation. The infrastructure-agriculture tandem explained more than one third of the cases and was relatively evenly distributed across regions. In 90% of these cases, the extension of road networks caused extension of permanently cropped land and cattle pasture, thereby resulting in deforestation. The logging-agriculture tandem explained only 10% of all cases in the study but was an important direct driver of deforestation in Southeast Asia and parts of China: the leading specific driver in most Asian cases is commercial, chiefly state-run logging activities, leading to the expansion of cropped land.

21.6.1.2 Indirect Drivers

Indirect drivers of deforestation are fundamental social processes, such as human population dynamics or agricultural policies, that underpin the direct drivers and either operate at the local level or have an indirect impact from the national or global level (Geist and Lambin 2002). These indirect drivers fall into five broad categories: economic, policy and institutional, technological, cultural/sociopolitical, and demographic. Each of these is complex even at the level of a general typology. (See Table 21.7.) They are of course even more complex in particular countries and contexts, and, like direct drivers, indirect drivers rarely function alone.

Economic factors, particularly those related to economic development through a growing cash economy, are highly important across many regions. Many cases are characterized by the marginalization of farmers who have lost their resource entitlements, combined with development brought about through public or private investments (Geist and Lambin 2002).

Institutional factors are also frequently important and are closely tied to economic drivers. These may involve formal pro-deforestation policies and subsidies (for colonization, agricultural expansion, or logging, for instance) as well as ''policy failures'' such as corruption or forestry sector mismanagement. Property rights issues, although much discussed in the deforestation literature, were only a major indirect driver in the cases Geist and Lambin analyzed for Asia and tended to have an ambiguous effect on forest cover: both tenurial insecurity (such as open access conditions and denial of indigenous land rights) and the legalization of land titles (enhanced tenurial security) were reported to influence deforestation in a similar manner. While property rights issues may not be the most dominant factors driving deforestation, it is widely recognized that clear property rights are a fundamental basis for instituting sustainable forest management. (See Box 21.5.)

Among demographic factors, only in-migration of colonists to sparsely populated forest areas appeared to be significant; population increase due to high fertility rates has not been a primary driver of deforestation at a local scale or over a few decades. Population increases are always combined with other factors (Geist and Lambin 2002).

21.6.1.3 Summary of Drivers

In summary, while it is possible to identify with some certainty the factors underlying tropical deforestation in a general sense, it is very difficult to pinpoint a uniform set of drivers and their relative contributions that can be said to apply generally at a global or even regional level. In a separate review of 140 models analyzing the causes of tropical deforestation, Angelsen and Kaimowitz (1999) raised significant doubts about many conventional hypotheses in the debate about deforestation; they found that more roads, higher agricultural prices, lower wages, and a shortage of off-farm employment generally lead to more deforestation, although how technical change, agricultural input prices, household income levels, and tenure security affect deforestation remains unknown. The role of macroeconomic factors such as population growth, poverty reduction, national income, economic growth and foreign debt was also found to be ambiguous. Moreover, the study found that the ''win-win'' hypothesis that economic growth and removal of market distortions will benefit both people and forests is not well supported by the available evidence. Rather, economic liberalization and currency devaluations tend to yield higher agricultural and timber prices that, in general, will promote deforestation (Angelsen and Kaimowitz 1999).

21.6.2 Temperate and Boreal Forest Ecosystems

Contrary to the situation in tropical forests, an important feature of forest dynamics in temperate and boreal zones is natural reforestation and expansion of forests. This process has been typical for the entire boreal zone during the last 40 years, and in Northern Eurasia this was due largely to the great restoration potential of boreal forests and the suppression of fire from the 1960s to the mid-1990s (Shvidenko and Nilsson 2002). Data for North America are less available, but fragmented satellite observations suggest that reforestation and forest expansion has been common for the entire circumpolar zone. Indeed, many temperate counties have initiated programs of reforestation and improvement of existing forests (UNECE/FAO 2003), resulting in increased net forest cover in temperate and boreal forest ecosystems.

Drivers of increasing forest cover in temperate industrial countries include the intensification of agriculture and agricultural overproduction, resulting in set-aside policies; loss of soil fertility; the increasing value of forests' amenity services; climate protection and watershed protection uses; and growing public understanding of the environmental values of forests.

In Europe, many forests were cleared centuries ago to allow agricultural expansion. Some of that agricultural land has become uneconomic to farm (see Chapter 26); meanwhile, the values of other forest services (amenity, conservation and protection, timber) have increased. Thus, the economically optimal land use has changed over the last century and trees have been either replanted or allowed to regenerate naturally. A number of countries in Europe have developed national polices aimed at conversion of some agricultural and marginal land into forest. And in Russia, the economic situation and social changes during the past decade have led to abandonment of over 30 million hectares of arable land, which is regenerating naturally into forest, trees, and bushes (Kljuev 2001).

Forest quality, however, has not necessarily improved across the temperate and boreal zones. Indeed, forests in Europe showed

Table 21.7. Generalized Typology of the Indirect Drivers of Tropical Deforestation (Adapted from Geist and Lambin 2001)

Economic change (economic growth, development, commercialization)	market growth and commercialization	rapid market growth (especially exports), rise of cash economy, increasing commercialization, incorporation into global economy increased market accessibility (especially of semi-urban and urban markets) lucrative foreign exchange earnings growth of demand for forest-related consumer goods due to rise in well-being
	specific economic structures	large individual (mostly) speculative gains poverty and related factors economic downturn or crisis indebtedness, heavy foreign debt
	urbanization and industrialization	urbanization; growth of urban markets industrialization: rapid expansion of new basic, heavy, and forest-based or forest-related industries
	special economic parameters	comparative advantage due to cheap, abundant production factors in resource extraction and use artificially low-cost production conditions (e.g., through subsidies) price increases or decreases for cash crops, fuel, land
Policy and institutional factors	formal policies	taxation, charges, tariffs, prices credits, subsidies, licenses, concessions, logging bans economic development (e.g., agriculture, land use policy, infrastructure) finance, investment, trade population (including migration and resettlement) other forestry sector policies
	informal policies (policy climate)	corruption and lawlessness growth or development coalitions bureaucratic mismanagement and poor performance clientelism, vested (private) interests role of civil society (e.g., NGOs)
	property rights regimes	insecure tenure and resulting open access in forest areas privatization of public lands state assertion of control over private, communal, or customary lands inequality in land access, ownership, and control
Technological change	agro-technological change	land use intensification land use extensification other changes (landholding, production orientation, etc.)
	technological applications in the wood sector	damage and waste due to poor logging performance waste in wood processing, poor industry performance lack of cheap technological alternatives to fuelwood; poor industrial and domestic furnace performance
	other production factors in agriculture	low level of technological inputs land-related factors (landlessness, land scarcity) labor-related factors (limited availability) capital-related factors (no credit, limited irrigation)
Cultural/socio-political factors	public attitudes, values, and beliefs	public unconcern or lack of (public and political) support for forest protection and sustainable use; low educational levels; frontier mentality; dominance of other public values (e.g., modernization, development) unconcern about the welfare of others and future generations; low perception of public citizenship and responsibilities beliefs about how environmental change affects other things that individuals value
	individual and household behavior	unconcern by individuals about the environment as reflected in increasing levels of demands, aspirations, and consumption, commonly associated with commercialization and increased income situation-specific behavior of actors: rent-seeking, nonprofit orientation, extent of adherence to traditional resource use modes
Human population dynamics	population growth, density, spatial distribution, and life cycle features (e.g., age, gender structure)	

BOX 21.5

Influence of Property Rights on Forest Cover Change and Forest Management

From the colonial period until recently, governments have legally owned most forests. The tradition of government ownership originated in medieval Europe and was transported to most colonies and adopted by imperial states in the sixteenth and seventeenth centuries (White and Martin 2002). Except for in the United States, Mexico, China, and Papua New Guinea, government ownership of forests spread throughout Africa, the Americas, and South and East Asia as new governments took rights from native peoples and centralized the control and management of forest resources in public forest agencies. Currently, about half (51%) of forests and other wooded lands are in public ownership in Europe (without Russia) and the rest is privately owned. National variation of ownership in temperate and boreal countries is significant: in a number of countries (such as Canada, Russia, Ukraine, and Bulgaria), forests and OWL are almost exclusively owned publicly; in others, forests are owned privately (for example, 92% in Portugal, 82% in Austria, and 80% in Sweden) (UNECE/FAO 2003).

By 1982, over 80% of the closed forests in developing countries were public land (FAO 1982). A 2002 study (White and Martin 2002) estimated that about 77% of the world's forest are owned and administered by governments based on national laws, at least 4% are reserved for communities, at least 7% are owned by local communities, and approximately 12% are owned by individuals. (See Table.)

In general, governments in countries with large amounts of forest have traditionally opted to transfer access rights and management authority to large-scale private industry through logging concessions. Gillis (1992) estimated that in 1980 about 90% of all industrial roundwood was derived from logging concessions. Data from 16 countries in Africa, the Americas, and Southeast Asia for which concession information is available reveal that 396 million hectares (44.2% of the total forest area) are under concessions. In some of these areas, particularly in Southeast Asia, the access and use rights granted to forest concessions have contributed to the massive exploitation of forest resources and the marginalization of forest-dependent communities (Broad 1995; Kummer 1992).

In the last decade or so, some governments have introduced reforms in forest ownership policies in favor of community access and ownership. These reforms were propelled by at least three factors: government recognition of the claims of indigenous and other local communities; growing evidence of the capacity of local communities to carry out sustainable forest management, due to their traditional management practices and their direct stake in forest sustainability; and the increasing realization that governments and public forest agencies have often not been good mangers of public forests (White and Martin 2002). Currently, small farms, communities, and indigenous people own or have usufruct rights over one fifth of forests in developing countries. India's Joint Forest Management Programme can be cited as one generally positive example of implementation: over 35,000 village organizations now participate in the program, covering 18% of all state forests where 147 million people live in and around forests (Forest Trends 2002), although the process is not simple and the results have not all been positive (Arnold 2001).

Social conflicts often accompany the process of change and redistribution of property rights, in particular use of lands of indigenous communities for industrial forestry and agricultural purposes, including forcible or illegal seizure of land. Reservation of indigenous territories is considered an important tool for conserving natural forests in many countries, particularly in the tropics. Recognized indigenous territories constitute 20% of the Brazilian Amazon, for example. Conflicts, however, between indigenous peoples in these territories and newcomers—such as illegal farmers associated with the Landless Rural Workers Movement—are quite common.

There is no single, "correct" forest property rights regime for all cases. Each country must find its own balance among public, private, and community rights. Whatever particular balance a country strikes, however, forest property rights need to be clear and enforceable. Formal legal establishment of property rights does not guarantee their effective implementation or enforcement. In many developing countries (and some countries in transition), forest property rights are legally mandated but are not implemented due to weak enforcement capacity or corruption.

Estimated Distribution of Forest Ownership for Selected Categories (White and Martin 2002)

	Public		Private	
	Administered by Governments	Reserved for Community and Indigenous Groups	Community/ Indigenous	Individual/Firm
Categories	*(percent of total)*			
Global forest estate	77	4	7	12
Developing countries	71	8	14	7
Developed countries	81	1	2	16
Tropical countries	71	6	13	10
Top 17 megadiverse countries	65	6	12	17
Top five roundwood products	80	7	6	7

a continuous deterioration from 1986 to 1995 due to air pollution, with the proportion of healthy trees falling from 69% in 1988 to 39% in 1995. Results for 1995–2001 show stabilization at a high level of damage, with almost a quarter of the sample trees rated as damaged due to air pollution (EC-UN/ECE 2002). For example, sulfur from the world's biggest source of sulfur emissions, Norilsk in northern Siberia (about 2 million tons of sulfur dioxide per year), caused tree mortality and degradation of more than 2 million hectares of surrounding forest tundra landscapes during the last four decades (Nilsson et al. 1998; Bruce et al. 2004).

Air pollution induces changes in tree physiology, phenology, and biochemical cycling. Among air pollutants affecting forest health, sulfur, nitrogen, heavy metals, and ozone are the most pervasive, although the complexity of forest decline in relation to air pollution suggests that decline in condition has been due to the combined impacts of eutrophication, acidification, and climate change (Nelleman and Thomsen 2001; see also Chapter 25).

The impacts of pollution on forests are not confined to industrial countries. Although anthropogenic emissions of sulfur dioxide have recently declined in most industrial countries in Europe and North America, emissions have increased in a number of countries of Asia, Africa, and Central and South America. Emissions of nitrogen oxides due to human activities remain constant or have increased over vast regions. (See Chapter 13.)

Pest outbreaks also seriously affect the quality of temperate and boreal forest ecosystems. Between 2000 and 2003, harmful forest insect outbreaks in Canada and Siberia affected more than 20 million hectares of boreal forests. The area affected by bark beetles in British Columbia increased during 2002–03, doubling to 4.2 million hectares (Berg and Henry 2003), from which the expected loss of timber is estimated to be CAN$20 billion, in addition to the increased risk of catastrophic fires. In northern Siberia, more than 10 million hectares of larch forests were defoliated by Siberian silkworm in 2001 and 2002 (MNR 2003). The main underlying cause of these increases in natural disturbances in the boreal zone was the extremely hot and dry summers and mild winters that occurred between 1998 and 2003 (e.g., Ivanov 2003).

21.6.3 Fires in Forest Ecosystems

Fire is a crucial disturbance factor affecting tropical, temperate, and boreal forests. In many regions (the boreal zone, for instance, and savannas), fire is an essential and ecologically important process that organizes structure and functioning of forest ecosystems and substantially affects flows of energy and matter. For many other forest ecosystems, however, fire is a negative factor that severely damages forests and can lead to long-term degradation (FAO 2001e; WGWF 2003).

The incidence and severity of forest fires appears to have accelerated over the past few decades (Kasischke and Stocks 2000). (See also Chapter 16.) Until recently, for example, fire in tropical evergreen forests had a negligible distribution and impact. However, tropical rain forest conversion to rangeland and agricultural systems, slash-and burn practices, and landscape fragmentation, exacerbated by the El-Niño Southern Oscillation, have resulted in the dramatic increase of wildfires in tropical rain forests during the last two decades (Muller-Dombois and Goldammer 1990; WGWF 2003; Mutch 2003).

The El Niño–driven fires of 1997–98 burned more than 20 million hectares in Latin America and Southeast Asia. The burnt area in Kalimantan (Indonesian Borneo) alone was about 6.5 million hectares, of which 3.2 million hectares was forest or forest areas that had recently been severely degraded or converted to plantations and other agricultural uses (Tacconi 2003). The complete economic, social, and ecological consequences of these fires have not been quantified, although some studies have yielded at least partial estimates of lost wood and impacts on wildlife and human health (e.g., Barber and Schweithelm 2000; WWF-Indonesia and EEPSEA 1998). The cost of carbon loss from the forests due to the 1998 fires in Latin America is roughly estimated at $10–15 billion, and severe respiratory health problems together with widespread transport disruption were estimated to cost $9.3 billion (WGWF 2003).

Increased fire activity has also been observed in other forest biomes. During the last two decades, forest fires in boreal North America (Canada and Alaska) have burned an average of 3 million hectares annually (national statistics available from the Global Fire Monitoring Center, www.fire.uni-freiburg.de). Apart from the influence of weather, shortcomings in forest fire management contributed to this increase. Human activities since 1900 have altered forest structure and fuel loadings to such an extent that they have eliminated the natural fire regime on over half the land area (260 million hectares) of the conterminous United States (Schmidt et al. 2002). In 2002, about 3 million hectares of U.S. forests burned, causing the deaths of 21 firefighters. In Russia, about 15 million hectares of forest burned in 2003. In that same year, forest fires destroyed 5% (386,000 hectares) of Portugal's forest and killed 20 people (the average annual burned area during the previous decade was about 50,000 hectares (Baptista and Carvalho 2002)), and the official estimate of economic damage of fire in 2002 was about $1 billion.

Although an inventory of the global fire situation was prepared as part of FRA-2000 (FAO 2001d), available national information is incomplete, and the certainty of data for many regions in unknown. The satellite-based Global Burned Area Product for the year 2000 reported the global burned area of terrestrial vegetation to be 351 million hectares (JRC 2000). The reliability of this estimate is not known, however, due to the coarse resolution of the remote sensing data used and the absence of ground-truthing for many large regions. Nevertheless, the main conclusion is evident: forest fires have become a global factor negatively affecting the condition and functioning of terrestrial biota, and experiences over the past decade show that the risk and threats of forest fires are widespread across the globe.

21.6.4 Climate Change and Forests

During the last 30 years the world has experienced significant temperature increases, particularly in northern high latitudes (IPCC 2001a). (See Chapter 25.) The climatic scenarios considered by the Third Assessment Report of the IPCC projects the increase in global annual average surface temperature by the year 2100 to be 1.4–5.8° Celsius higher than the mean over the period 1990 to 2001. In some regions, this projected warming will generate a climate not experienced in recent evolutionary history. Western North America, for example, could be 2–5° Celsius above the range of temperatures that have occurred over the past 1,000 years, and vast regions in Siberia could be warmer by 6–10° Celsius. Moreover, temperatures are projected to continue to increase beyond 2100 even if atmospheric concentrations of greenhouse gases were to be stabilized by that time (Houghton et al. 2001).

As a whole, precipitation patterns are also predicted to increase, although this is mostly expected in winter precipitation, and many regions will face either a very small change or a decrease in summer precipitation. In particular, the latter is expected in regions of dry forests and woodlands. Finally, climate variability, such as the frequency of extreme events and occurrence of dry and hot periods, are expected to increase substantially (IPCC 2001a, 2001b).

These dramatic changes will be accompanied by the "fertilization effect" of increasing CO_2 concentration and nutrient deposition, which may substantially affect the state, functioning, and dynamics of the world's forests (Chapin et al. 2004). Although there is a lack of knowledge on the adaptive capacity of tree species, it is likely that an increase of temperature of a few degrees may accelerate productivity of forests, but any further increase will affect forest ecosystems in a clearly negative way (Walker et al. 1999). In spite of the fact that many experiments with leaves, shoots, and tree seedlings indicate a significant increase of productivity due to CO_2 fertilization, these effects on forests will be saturated in a short time (Scholes et al. 1999). There are also experimental data that do not support CO_2 fertilization models (Pacala 2004).

In many regions, adaptation of some forests, such as those on peat and wetlands covered by trees and shrubs, may be practically impossible. Melting of permafrost at high latitudes will cause dramatic changes in hydrological regimes of huge areas (Chapin et al. 2004). Satellite-based measures of the greenness of the boreal forest zone indicate a lengthening of the growing season over the past two decades (Nemani et al. 2003). In dry forests, net decreases in available soil moisture will decrease forest productivity. Many of these regions are also affected by El Niño/La Niña and other climatic extremes, and significant increases in land degradation and impoverishment of forests are likely (IPCC 2001a, 2001b).

Tropical montane cloud forests are especially vulnerable to climate change (Markham 1998). Various lines of evidence show that these have already been affected by climate change (Bubb et al. 2004), either through declines in the species they support (Pounds et al. 1999) or through rising cloudbanks (Still et al. 1999), which are a consequence of both climate change and regional land use change (e.g., see Lawton et al. 2001).

However, the degree to which changes in climate have already affected (e.g., see Walther et al. 2002) and continue to affect (Aber et al. 2001) productivity indicators of forests and their ability to supply services varies across space and time. This is because of the varying life cycles of forests, where climate changes within the former life cycle have a more immediate effect on regeneration success following disturbances (Price et al. 1999a, 1999b); differing values placed on forests by society (Spittlehouse 1997); disagreement on whether impacts of climate change are positive or negative (Körner and Arnone III 1992); and the varying priorities of governments for addressing other impacts (Spittlehouse 1997).

The impacts of changing climate also vary among different measures of ecosystem productivity. For example, because short growing seasons and the sum of active temperatures are the main factors limiting growth in boreal and alpine forests (Stewart et al. 1998), a projected increase in temperature may lead to higher net primary productivity values in most of these forest stands (Bugmann 1997, but see possible limitations in Barber et al. 2000), while net ecosystem productivity values will show decreases due to increased decomposition (Valentini et al. 2000, but see Giardina and Ryan 2000). On the other hand, should higher temperatures together with lower summer precipitation values occur in these forest stands, then harsher summer drought conditions may decrease NPP values as a result of lowered photosynthetic rates associated with reduced stomatal conductance (Sellers et al. 1997). Such a scenario will lead to a further decrease in NEP values due to decomposition.

The possible negative climatic effects caused by drought could be partly or fully mitigated by elevated CO_2 levels. High CO_2 levels have been found to be associated with increased photosynthetic rates and increased water use efficiency of various forest species; this could potentially lead to increased forest productivity. Evidence for this, however, is still inconclusive (Kirschbaum and Fischlin 1996). In humid evergreen tropical forest in Costa Rica, annual growth in the period 1984–2000 varied inversely with the annual means of daily minimum temperature because of increased respiration at night (Clark et al. 2003). On the other hand, a network of Amazon forest inventory plots shows a carbon accumulation rate of 1 ton of carbon per hectare per year since 1979 (Baker et al. 2004). Tree recruitment and mortality have increased significantly in the Amazon in the past two decades, with recruitment consistently exceeding mortality (Phillips et al. 2004).

Finally, warmer and drier conditions will result in increased forest and woodland fires (Laurance and Williamson 2001; Kasischke and Stocks 2000), leading to reduced transpiration and increased carbon emissions and thus creating a positive feedback whereby more-frequent and severe fires result in complete deforestation (Cochrane et al. 1999). It has been estimated that in 1997–98 net forest fire emissions (from biomass and soil losses) may have released carbon that was equivalent to 41% of worldwide fossil fuel use (Houghton et al. 2001). Therefore drier conditions will clearly add pressure to both ecosystem services (such as negative net biome productivity) (Apps et al. 2000) and the economic potential of these natural resources (see Dixon et al. 1994 for the economic importance of forests) and will also affect human health due to smoke-related impacts as a result of forest fires (Cochrane 2003).

Because climate change alters the spatial and temporal patterns of temperature and precipitation (the two most fundamental factors determining the distribution and productivity of vegetation), climate change will cause geographical shifts in the ranges of individual species and vegetation zones. In West Africa, lower rainfall and higher temperature due to climate change and desertification have shifted the Sahel, Sudan, and Guinean vegetation zones 25–30 kilometers southwest toward areas of higher rainfall and lower temperature in the period of about 1945–93 (Gonzalez 2001). In New Mexico in the United States, a 1954–58 drought caused a permanent 2-kilometer shift of xeric piñon-juniper woodland into mesic ponderosa pine forest (Allen and Breshears 1998), and some climate modeling shows extensive latitudinal and altitudinal shifts of vegetation zones across North America and Siberia (Iverson and Prasad 1998; Pan et al. 1998; Bachelet et al. 2001).

The dynamic nature of the environment within which sustainable forest management must take place means that simple representation of the more tangible forest elements, such as productivity indicators, in static areas (such as protected areas) is unlikely to be sufficient for long-term protection and hence sustainability (Stewart et al. 1998; Rodrigues et al. 2000; Hannah et al. 2002). Consequently, flexible forest and woodland management will be needed to adapt to some of the effects of future climate change, which will certainly have widespread affects on forest and woodland systems (Dixon et al. 1994; Cohen and Miller 2001; Spittlehouse and Stewart 2003).

21.7 Human Well-being and Forests and Woodland Systems

Forests and woodlands supply essential services to human well-being across the world, and human-forest interactions manifest themselves in many direct and indirect ways, each depending variously on the amount of forest, its condition, and its distribution over the landscape.

More than 1.7 billion people live in the 40 nations with critically low levels of forest cover, in many cases hindering prospects for sustainable development. The number of people living in low-forest-cover nations will probably triple by 2025, reaching 4.6 billion, and 13 additional countries will experience forest resources scarcity (Gardner-Outlaw and Engelman 1999). Human population growth has drastically shrunk the forest-to-people ratio from 1.2 hectares per capita in 1960 to 0.6 hectares per capita at present. By 2025, the ratio is predicted to decline further, to 0.4 hectares per capita (Gardner-Outlaw and Engelman 1999).

The expected decline in the per capita availability of forests in developing countries generates additional problems for sustainable development. In many parts of the developing world, direct harvesting of forest products by rural families contributes to more than 50% of total consumption and other household needs (Cavendish 2000; Hassan 2002; Hassan et al. 2002; Godoy and Bawa 1993; Kusters and Belcher 2004; Peters et al. 1989; Sheil and Wunder 2002; Sunderland and Ndoye 2004). This large group of people is particularly vulnerable to the negative impacts of declining forest cover.

Diminishing access to forest products significantly affects human well-being in developing countries. Inadequate supplies of paper could emerge as a significant impediment to development during this century, and 80% of the world's population has yet to achieve the level of paper use deemed necessary to meet basic needs for literacy and a minimal level of education and communication (Gardner-Outlaw and Engelman 1999). About 2.4 billion people use energy derived from biomass, mostly from forests and woodlands (Arnold et al. 2003; see also Chapter 9), and most of the 240 million poor people in forested regions in developing countries depend heavily on forests and trees for their livelihoods (World Bank 2003).

Development of modern forest industries can generate local employment and thereby improve the standard of living of forest communities. Still, a significant proportion of wood harvested in tropical countries is exported as unprocessed logs. For instance, 38–48% of unprocessed roundwood was imported from net export African member countries of the International Tropical Timber Organization during 1995–2000 (Buttoud et al. 2002), and domestic demand for wood products in these countries remains very low, at around 0.1 cubic meters per person a year for timber.

Population-related pressure on forests is greatest in countries where per capita forest cover is low, and although forests are often protected or planted as population pressures increase, this is usually only in high-productivity zones (such as Bangladesh, Java, parts of Kenya, and India) but rarely in areas of low productivity (Persson 2003). Many countries in the developing world are facing local woodfuel and NWFP scarcity, and the situation is expected to become more acute (FAO 2003a). Because it is often women and children who search for fuel and edible forest products and so on, such shortages have particularly negative impacts on these sectors of the population.

Of course, not all deforestation is necessarily undesirable, and many areas of forest have been lost after the negative consequences of such loss have been carefully considered and weighed against the benefits. For many countries, past and present, converting some forestlands to agricultural, infrastructural, industrial, and urban uses has been a necessary and accepted mechanism for economic development and progress. Unfortunately, deforestation, particularly in the tropics, has often resulted in conversion to unsustainable land uses and has not delivered the anticipated benefits to economic development.

It is projected that tropical deforestation will likely continue unabated through 2020 and that demand for fuelwood will continue to rise in Africa and some other regions of the developing world, watershed protection will continue to deteriorate, and countries will not likely improve efforts to implement sustainable forest management (FAO 2003a; Kaimowitz 2003). National forest services generally remain underequipped to counter these trends. A survey of government expenditures in 24 African countries in 1999 showed that forest expenditures averaged 82¢ per hectare, of which international financing accounted for 37¢ (FAO 2003a). Most national funding goes to staff salaries, while the international component generally goes to investments in material and information systems.

The condition of forests in individual countries and the well-being of forest-dependent peoples are closely tied to economic development levels and trends. Russia is an interesting and informative example, as the severe economic situation of the last 15 years has led to large-scale decline of the forest sector. The production of major forest products decreased between 1988 and 1998 by three- to fivefold (Bourdin et al. 2000), dramatically affecting the well-being of about 3 million people in regions where forests are a major source of employment and subsistence. Many hundreds of forest settlements now suffer from unemployment and a lack of basic living conditions; subsistence farming, gathering mushrooms and wild berries and fruits, fishing, and poaching have become major sources for subsistence in many forest regions. This situation is heavily influenced by an inadequate forest policy, although in recent years there has been a slow but evident restoration of the Russian forest sector, driven largely by market mechanisms (Shvidenko 2003).

The extent and distribution of forests are important at all spatial levels, from the local to the continental. Even if a country as a whole has a sufficient amount of forested area in the aggregate, forest cover in particular regions or landscapes may still be insufficient to meet the demand for services. Redistribution of forest cover over a landscape is difficult, however, and requires long-term, consistent policies at the national level. Improving the condition of forests and their contribution to human well-being is an important and urgent task, both nationally and internationally. Recent history, such as international efforts working with the Tropical Forestry Action Plan (FAO 1985; Winterbottom 1990), clearly shows both how difficult it is to achieve sustainable forest management in the contemporary world and that many problems remain to be solved in order to realize the potential benefits that forests and woodlands have to offer.

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