Chapter 9

Timber, Fuel, and Fiber

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Main Messages

Global timber harvest has increased by 60% in the last four decades and will continue to grow in the near future, but at a slower rate. The growth rate of timber harvest has slowed in recent years and is likely to continue to grow more slowly in the foreseeable future. (In this chapter, "timber" is used to denote standing trees and their immediate products). The portion of harvested wood that was used for pulp increased threefold since 1961, reflecting a major shift in demand for timber products as pulpwood demand greatly outpaced the increased demand for sawn wood products.

Timber supplies for common industrial wood products appear to be ample for the near future, but there will be shortages of high-value species and premium quality woods due to past overharvesting. Timber production from both forest and agricultural plantations will increase over the near future, providing wood for pulp and common sawtimber. Premium woods from large and old trees of highly valuable species are scarce in most regions. They may be restored through protection and sustainable forest management in the longer term but will remain in short supply for the foreseeable future.

Plantations are providing an increasing proportion of timber products. In 2000, plantations were 5% of the global forest cover, but they provided some 35% of harvested roundwood, an amount anticipated to increase to 44% by 2020. The most rapid expansion will occur in the mid-latitudes, where yields are higher and production costs lower. Gains in production will also come from insect and disease-resistant trees, genetically improved trees with higher yields and improved fiber characteristics, improved planting techniques, and improved management. The net effect will increase the amount of products available to satisfy timber, fuel, and fiber needs, but with a reduced harvest from natural forests in most regions.

Major shifts in the location of timber production have resulted from a combination of globalization, economic stress, and changing national policies, and the future for sustainable timber supplies varies across areas and regions. In general, recent production shifts have been from north to south. In the northern boreal and temperate regions, forest-growing stocks have increased in the recent past, as overall annual growth has exceeded mortality and harvest. This trend will continue into the foreseeable future (*medium certainty*). In the low latitudes, deforestation and degradation continue to diminish natural forests. Contributing to this are examples of destructive, exploitive, and illegal logging practices. These combine with a complex of other drivers, including fuelwood extraction, agricultural expansion, development policies, and population pressures to contribute to forest degradation. The associated production losses are partially offset by plantation expansion, but premium species are seldom replaced, either in regrowing forests or in plantations.

International trade in forest products has increased at a rate much faster than the increase in production. The global value of timber harvested in 2000 was around $400 billion, and around one quarter of that entered into world trade, representing some 3% of total merchandise trade. In constant-dollar terms, global exports increased almost twenty-five-fold between 1961 and 2000. Five countries—the United States, Germany, Japan, the United Kingdom, and Italy—imported more than 50% of world imports in 2000, while Canada, the United States, Sweden, Finland, and Germany accounted for more than half of exports. During the past decade, China has increased its imports of logs and wood products by more than 50% and, if unabated, this rate of increase will put significant pressure on wood supplies in many regions, particularly Russia and Southeast Asia.

International moves toward sustainable forest management and forest certification have expanded rapidly in recent years. To date they have been used primarily in industrial countries, and only locally in developing countries, and they do not seem to be affecting timber production or trade significantly. They are, however, affecting forest management where certification is involved. Their broad future effectiveness remains uncertain, but they could become more important in some regions, such as Europe.

The global forestry sector annually provides subsistence and wage employment of 60 million work years, with 80% taking place in the developing world. While timber is processed mainly by industrial firms, the management of forests, including harvesting and transport, is dominated by individuals, families, and small companies. In the industrial world, the forestland is both privately (in Europe and the United States, for example) or publicly (as in Canada) owned and managed. In the developing world, most of the forest is a public resource. These ownership factors create very different and diverse opportunities for people to interact with and benefit from forest products and services. As production moves South in the near future, the trend indicates increasing forest employment opportunities in sub-tropical and tropical regions, with declining employment in temperate and boreal regions. Labor requirements per unit of output in all regions will continue to shrink due to technological change.

Illegal logging is a significant factor that skews timber markets and trade, particularly in tropical forest regions and countries with weak or transitional governments. It is estimated that up to 15% of global timber trade involves illegal activities, and the annual economic toll is around $10 billion. Addressing this problem will require a major effort by both governments and private industry.

On a global basis, the recorded value of fuelwood production per capita has fallen in recent years, and earlier concerns about a "wood energy crisis" have eased. Fuelwood is the primary source of energy for heating and cooking for some 2.6 billion people, and 55% of global wood consumption is for fuelwood. While populations in developing regions will continue to grow, estimates from FAO indicate that global consumption of fuelwood appears to have peaked in the 1990s and is now believed to be slowly declining. Accurate data on fuelwood production and consumption are difficult to collect, since much of it is produced and consumed by households in developing countries. It is also difficult to relate trends to ecosystem condition, since fuel is harvested from woody plants wherever they occur. Localized fuelwood shortages in Africa impose burdens on people who depend on it for home heating and cooking. The impact on people may be high prices in urban areas or lengthy and arduous travel to collect wood in rural areas.

The burning of wood fuel without appropriate smoke venting creates significant health hazards, and where wood shortages force poor families to shift to dung or agricultural residues for heating and cooking, the problems are exacerbated. An estimated 1.6 million deaths and 39 million disability-adjusted life years are attributed to indoor smoke pollution, with women and children most affected. Where adequate fuel is not available, the consumption of cooked food may decline, leading to adverse effects on nutrition and health. Human well-being can be enhanced in many developing regions through efforts to assure adequate and accessible fuel supplies, as well as to promote more-efficient stoves and more-effective smoke venting.

Wood and forest biomass, agricultural crops and residues, manure, municipal and industrial wastes, and many other non-fossil organic materials can produce renewable energy and fuel supplies through a variety of modern industrial processes. These renewable energy technologies are being rapidly developed throughout the world, but examples of full commercial exploitation are still fairly modest. Competition from low-cost and widely available fossil-based fuels currently limits the expansion of successful research and pilot projects into widespread commercial production. Biomass-based energy production, while likely to expand slowly in the near future, offers great promise for the mid- and long-term future, as the nonrenewable nature of fossil fuels, particularly natural gas and petroleum crude oil, begins to affect energy economics because of shortages and supply disruptions.

Global cotton production has doubled and silk production has tripled since 1961, accompanied by major regional shifts in the production areas. Production of other agricultural fibers such as wool, flax, hemp, jute, and sisal has declined. While cotton production has doubled, the land area on which it is harvested has stayed virtually the same. Major area expansion of cotton production in India and the United States has been offset by large declines in Pakistan and the former Soviet Union. These shifts have important impacts on limited water resources, since much of the cotton crop is irrigated, and on agricultural land use patterns, as cotton competes with food crops for arable land. There have also been significant impacts of the use of fertilizer and pesticides for the increased production of cotton. Silk production also experienced a major shift in production area, from Japan to China, due to lower labor costs.

There are still instances where species are threatened with extinction due to the trade in hides, fur, or wool, in spite of international efforts to halt poaching and trade. On the other hand, there are instances, such as for crocodiles, where international conservation efforts have restored species and established sustainable production of valuable commodities.

9.1 Introduction

This chapter on timber, fuel, and fiber covers a wide range of ecosystem services provided by an equally wide range of ecosystems. The major focus is on timber that is linked most closely with forest ecosystems and forest-related communities and industries, but it extends to fuel and fibers as well. Information about recent trends in supply and consumption of those products is presented and assessed in terms of the impact of that consumption on ecosystems and human well-being, and efforts are made to identify and assess the important drivers of change in each resource area. Trends in the condition of the ecosystems from which these services are derived are found in other chapters of this volume (particularly Chapters 21, 22, and 26).

Forests cover about 30% of the ice-free land area of Earth, but global forest cover has declined considerably through history (FAO 2001a; Williams 2003). (See also Chapter 21.) While there are copious statistics for the timber and wood products that enter into world trade, assessing the connection between production and forest ecosystems is complicated by the fact that the production statistics are reported by country rather than by biome or ecosystem.

The most complete and comparable statistics are maintained by the U.N. Food and Agriculture Organization, and its publications and databases are widely cited in this chapter. It should be noted that all statistics on wood production, whether for fuel or commercial purposes, have some limitations. Regional data are reported by FAO, but the regions are geographic or geopolitical, making their direct use in reflecting effects on forest ecosystems of limited value. For this assessment, FAO country data have been regrouped to approximate the dominant forest systems affected by the production trends reported. Table 9.1 lists the countries that were grouped into the seven major forested regions chosen for

Table 9.1. Regions Used in the Wood Products Analyses. The regions group countries with areas of closed forest by continent and climate type. (FAO 2003b)

Africa Tropical
- Angola
- Benin
- Cameroon
- Central African Republic
- Congo (Dem. Rep.)
- Congo (Rep. of)
- Côte d'Ivoire
- Equatorial Guinea
- Ethiopia
- Gabon
- Ghana
- Guinea
- Guinea-Bissau
- Liberia
- Madagascar
- Mali
- Mozambique
- Nigeria
- Senegal
- Sierra Leone
- Togo
- Zambia

America Temperate
- Canada
- United States

America Tropical
- Belize
- Bolivia
- Brazil
- Colombia
- Costa Rica
- Dominican Republic
- Ecuador
- El Salvador
- French Guiana
- Guatemala
- Guyana
- Haiti
- Honduras
- Mexico
- Nicaragua
- Panama
- Paraguay
- Peru
- Suriname
- Venezuela

Asia Temperate
- Bhutan
- China (PR)
- Japan
- Korea (DPR)
- Korea (Rep. of)
- Mongolia
- Nepal
- Russian Federation
- Turkey

Asia Tropical
- Bangladesh
- Brunei Darussalam
- Cambodia
- India
- Indonesia
- Laos
- Malaysia
- Myanmar (Burma)
- Papua New Guinea
- Philippines
- Sri Lanka
- Thailand
- Viet Nam

Europe Temperate
- Albania
- Austria
- Belarus
- Belgium
- Bosnia and Herzegovina
- Bulgaria
- Croatia
- Czech Republic
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- Ireland
- Italy
- Latvia
- Liechtenstein
- Lithuania
- Luxembourg
- Macedonia (FYR)
- Moldova
- Netherlands
- Norway
- Poland
- Portugal
- Romania
- Serbia and Montenegro
- Slovakia
- Slovenia
- Spain
- Sweden
- Switzerland
- Ukraine
- United Kingdom

Southern Temperate
- Argentina
- Australia
- Chile
- New Zealand
- South Africa

this assessment. Figure 9.1 (in Appendix A) indicates where these seven regions are.

In addition to timber, fuels derived from biomass are also considered in this chapter. More than 2 billion people worldwide rely on biomass for their main energy source (IEA 2003). Although wood and charcoal are the primary energy sources in many societies, particularly developing ones, the data for assessing the impacts of this use and consumption on ecosystem sustainability are largely unavailable. This is due to several factors, including the difficulty of monitoring the supply and consumption of wood fuels accurately, as much of it is done outside the market economy.

The last section of the chapter discusses some of the general trends in the production and consumption of important fibers derived from forest or agricultural crops, domestic animals, wildlife, and other sources. These products, each of which could be the subject of a major assessment, are treated sparingly due to limitations of space and time.

The ownership of forests varies on the basis of legal and cultural traditions and history. In some nations, central governments claim vast areas of forest but do little to enforce those claims. Poor administration and corruption allow illegal logging and other forms of resource extraction, including within protected forests. In other areas, highly developed property rights systems exist, and resource extraction is often tightly regulated as a result. More wood per hectare is generally harvested from private forests than public ones, because of more-intensive management and more-focused forest production objectives. While some private forests produce multiple benefits, many are managed mainly for timber. (See Table 9.2.)

For forests in protected areas, timber harvest may or may not be one of the management objectives. Even where forests are protected from harvesting in some protected areas, resource extraction (for commercial or local use) continues unabated owing largely to poor governance and corruption (WWF 2000; Khan et al. 1997; Smith et al. 2003; and see MA *Policy Responses,* Chapter 5).

In both temperate and tropical forests, many local communities have decision-making rights for the management of public forestlands. Such community forest management systems include joint forest management in India (TERI 2000) and nascent concession systems in Bolivia and Peru. In order to foster long-term maintenance of forest resources, communal forest management arrangements generally allocate all or part of the forest production revenues to the local community. While the amount of forest products produced under such arrangements remains negligible as a fraction of total global output, community management can produce significant positive local economic impacts.

Table 9.2. Some Key Differences Affecting Forest Product Derivation from Public and Private Forests

Category	Public Forest	Private Forest
Management regime	extensive	intensive
Protected areas	common	uncommon
Land use	multiple use	dedicated use
Management costs (dollar per hectare)	low	high
Illegal logging	common	rare to nil
Planted forests	uncommon	common
Species planted	mostly endemic	mostly endemic
Plantation forests	uncommon	common
Species planted	mostly endemic	mostly exotic
Production per hectare	variable	generally high

9.2 Timber and Related Products

While forests produce a wide range of services that are essential to human well-being, their major financial output consists of timber that can be used for a variety of manufacturing, building, fuel, and other materials. Timber is harvested from forest ecosystems (both intensively and extensively managed), forest and agricultural plantations, and trees outside forests. It should be noted that there is not always a clear distinction in the data and discussion of these issues between ''planted forests'' and ''plantations.'' (See Chapter 21.)

9.2.1 Industrial Roundwood

According to FAO, industrial roundwood includes wood for the following commodities: sawlogs, veneer logs, pulpwood, other industrial roundwood (used for tanning, distillation, match blocks, poles, piling, posts, pitprops, and so on) and, in the case of trade, also chips and particles and wood residues. Although the title ''industrial roundwood'' suggests that this is wood harvested by industrial companies, the majority of the timber harvested in the world is still harvested by individuals, families, and small operations using a variety of traditional and modern methods. This use of the term ''industrial'' is better understood to mean wood that is produced for sale into commercial channels for processing or end use.

9.2.1.1 Production

Production of industrial roundwood increased between 1961 and 1980 in nearly all regions, but the increase, which was slowing gradually before 1980, slowed considerably between 1980 and 2000. (See Table 9.3.) Some of this decline in the rate of increase reflects the demise of the Soviet Union and the associated dramatic reduction in timber production. Russian and other former Soviet Union timber production, in excess of 300 million cubic meters a year in Soviet times, declined to one fourth of previous levels.

As the former centrally planned economy moved toward greater use of markets, the subsidies received by the transport sector were largely eliminated and with it, the subsidy that allowed

Table 9.3. Industrial Roundwood Production, 1961–2000 (FAO 2003c)

Region	1961	1980	2000	1961–80	1980–2000
	(million cubic meters)			*(percent change)*	
Africa tropical	15	28	34	83	20
America temperate	335	478	625	43	31
America tropical	28	83	131	198	57
Asia temperate	282	336	239	19	–29
Asia tropical	34	101	86	199	–14
Europe temperate	286	352	377	23	7
Southern temperate	25	50	92	97	86
Other areas	13	19	25	50	36
Total	**1,018**	**1,446**	**1,610**	**42**	**11**

timber transport from the forests to distant processing facilities. In addition, the large declines experienced in Russian Federation GDP further depressed timber demand and production. A growing Russian economy together with new export markets, such as China, should revive some of the demand for Russian Federation wood products, and indeed timber production increased in the late 1990s. The transport subsidy is unlikely to return, however, and Russian timber production in the next decade will likely be substantially lower than in Soviet times.

9.2.1.1.1 Illegal logging

It should be noted that the FAO data (and Table 9.3) consist primarily of legally produced wood as reported to national governments, and so in regions where illegal logging is significant, the data may underreport the actual volume of timber harvested. It is difficult to estimate the magnitude of illegal removals, and quantitative estimates vary. But the amount of timber involved is both locally and globally significant. Contreras-Hermosilla (2002) estimates that as much as 15% of global timber trade involves illegalities and corrupt practices, amounting to annual losses in assets and revenues in excess of $10 billion. Curry et al. (2001) conclude that ''illegal logging is rife in all the major tropical timber producing countries,'' citing studies showing that 70% of log production in Indonesia (50 million cubic meters per year) is derived from illegal sources; 80% of logging in the Brazilian Amazon during 1998 was illegal, and half of all timber in Cameroon is sourced through illegal logging (WRI 2000b).

Illegal logging takes many forms, including logging timber species protected by national or international law; logging in protected or prohibited areas; logging without authorization; extracting more timber than authorized; timber theft and smuggling; and fraudulent transfer pricing and other corrupt accounting practices. Its negative impacts include the impoverishment of forest landscapes, governments and local communities that are deprived of significant forest revenues, the strengthening of organized criminal enterprises, and inducements for the corruption of law enforcement and other officials (Contreras-Hermosilla 2002).

National and local governments, being unable to appreciably reduce illegal logging, often play down its extent. In Russia, for example, according to government figures illegal logging over the past decade has amounted to 1% of legally permitted logging. Independent NGO and scientific assessments, however, estimate illegal logging to constitute some 20% of the total, with illegal exports of particularly valuable species in border areas being double the legally permitted volumes (Sheingauz 2001). In other areas too, weak or poorly enforced legislation has been ineffective in protecting forests from illegal logging (for example, in the Congo basin) (Global Witness 2002).

9.2.1.1.2 Forest plantations

All the following statistics refer to forest plantations as opposed to planted forests, with the distinction being, for the latter, the application of planting as one of several normal silvicultural techniques used to reforest harvested areas. Plantations, in contrast, are intensively managed, regularly spaced stands, often monocultures, often of exotic species, and usually with the production of wood as the main product (FAO 2000c). Forest plantations covered 187 million hectares in 2000, with Asia accounting for 62% (FAO 2001a). This total represented a tenfold increase (from 17.9 million hectares) since 1980 (FAO 2001a). In 2000, the annual rate of new planting was estimated at 4.5 million hectares, of which 79% was in Asia, and much of this in China and India. (See Chapter 21 for a more complete description of trends in plantation forests.)

Yields from tropical plantations are high—often in the range of 10–30 cubic meters per hectare per year for *Eucalyptus* and *Pinus,* with some species on favorable soils reaching yields as high as 50–60 cubic meters per hectare. Given the amount of research that has gone into improving yield from planted stocks, these yields are likely to continue to increase. Because of high yields and increasing area, plantations provide a continuously increasing portion of the world's timber supply. According to FAO (2001a), plantations were only about 5% of global forest cover in 2000, yet provided some 35% of global roundwood, an amount anticipated to increase to 44% by 2020.

Plantation growth rates and wood quality are likely to improve with each successive rotation, as trees embodying new genetic improvements are increasingly being used to replace the old technology embodied in the prior harvest. Thus far the genetic improvements have come primarily through conventional breeding techniques. However, there are substantial efforts under way to apply modern biotechnology, including genetic engineering, to industrial trees and plantation forests (Sedjo 2004). The degree of acceptance of genetically engineered (transgenic) trees remains uncertain. But based on experience with genetically engineered crops, there is reason to believe that the adoption of transgenic technology for trees will be variable.

9.2.1.1.3 Agricultural plantations

Plantations of agricultural and industrial crops such as rubber, coconut, and oil palm are increasingly important sources of industrial wood for the forest industries of Asia. It is estimated that there are some 27.4 million hectares of these crops in the region. Changing technology and markets are resulting in the conversion of formerly wasted by-product logs to products such as plywood, particleboard, paper, and lumber for furniture and other uses (Durst et al. 2004).

Rubberwood (*Hevea brasiliensis)* is estimated to cover some 9 million hectares, primarily in Indonesia, Thailand, and Malaysia. Planted originally for the production of latex, the trees mature at about age 30 and are then replaced. Prior to the emergence of milling technology in the late 1970s, the wood was either used for energy or disposed of in open burning. Today, it is estimated that over 6.5 million cubic meters are processed into sawn lumber, largely for furniture (Durst et al. 2004). Rubberwood is also used for manufacturing a variety of wood panels. This production, which eases pressure on many formerly used native species, is currently the basis for exports of almost $1.5 billion annually from Malaysia and Thailand (Durst et al. 2004).

Coconut palm (*Cocos nucifera*) is another agricultural crop with emerging value for the forest products industry. Its primary use is for coconut oil, but after age 60, when yields begin to decline, the palms are generally felled and replaced. Removing the downed stems from the plantation is important for controlling disease, and selling them for lumber production increases plantation revenues.

It is estimated that, throughout Asia, palm wood production rates of around 5 million cubic meters per year will be available for at least 20–30 years. After that time, the existing plantations will be replaced by higher-yielding dwarf varieties that produce less valuable lumber, but which may be useful for products such as panels (Durst et al. 2004).

Oil palm (*Elaeis guineensis)* plantations cover an estimated 6.5 million hectares in Asia and are grown on a 25- to 30-year rotation (Durst et al. 2004). While this is a huge potential in terms of biomass, research and development are needed to overcome limitations in the use of this species for wood products. That research is under way, and if the experience in developing and using other formerly ''unusable'' species is any guide, increasing industrial use is likely in the future.

9.2.1.2 Consumption

Between 1961 and 1991, the market value of global wood consumption more than doubled in real terms, growing at 2.7% per year (FAO 1999). In terms of processed wood products, sawnwood increased by 20%, wood panels by 600%, and paper by 350% between 1961 and 1991. These increases were achieved, in large part, through improved production efficiencies, recovery of wood residues for use in wood panels, and paper recycling (FAO 1999).

An increasing supply of wood products has begun to flow into China as that economy continues to develop rapidly. China is now importing 107 million cubic meters of wood, which represents an increase of more than 50% during the period 1997–2003 (Sun et al. 2004). The demand for imported wood has developed in part as a result of policies limiting domestic harvest levels. Imports are made up of raw pulp and paper largely coming from Canada and Russia and sawn lumber and logs from Russia, Malaysia, and Indonesia (Sun et al. 2004). Imports from Russia have resulted in continued forest loss in there through rapid logging of mature forests. (See Chapter 21.) Demand from China is expected to continue to grow, resulting in increased social, environmental, and economic effects, particularly in Russia and Southeast Asia.

The substitution of a variety of other materials for wood has contributed to relatively slow growth in global timber consumption in recent years. Steel studs (with up to one-third recycled content) are replacing wood in some markets of industrial countries, and vinyl has largely replaced wood as a siding material in North America. Plastics have replaced wood in some specialty applications—for example, to a large extent in the European window frame market. The use of metal roofing is growing rapidly in many parts of the developing world and, along with other products, it has largely replaced wood as a roofing material.

As premium quality and specialty woods have become scarce due to high-grading and other forms of unsustainable harvesting, there has been considerable replacement of traditional wood products by new products. Solid hardwood furniture has been replaced in many situations by a thin veneer of hardwood glued to a manufactured panel. Solid boards for sheathing buildings have been replaced, first by plywood and then by composite oriented strandboard. Solid wood joists for flooring systems are being replaced by engineered I-joists fabricated from smaller pieces of wood from widely available second-growth trees that often do not produce the large and high-strength pieces needed for solid wood structural timbers. These I-joists offer a flatter floor, greater strength, and longer spans. These manufactured wood products are so far largely confined to markets in industrial countries.

In many parts of the world, newly engineered forms of wood flooring, often with sturdy artificial overlays, are gaining wide acceptance. Other new products include engineered panels for nonstructural uses such as furniture, flooring, and moldings. These are often constructed using sawdust, shavings, and other residuals from sawmills or plywood mills. Viet Nam has a plan to build as many as nine particleboard plants to support its growing furniture industry. Non-wood fibers are increasingly being tapped for these products; examples include panels from wheat straw in the North American wheat belt, and medium density fiberboard produced from oil palm stalks in Malaysia and Indonesia. Like many new technologies, the agri-fiber panels have had difficulties with some early testing. However, the technology seems well adapted for fiber-short nations with growing economies, such as China.

In the paper industry, plastics and other materials have replaced some paper bags, packing papers, and paperboard. Increasing use of recycled fiber has caused roundwood use for paper in the United States to decline significantly since the mid-1990s. Markets for many paper products in North America are saturated, and low economic growth in areas like Europe and Japan, driven by sluggish economic growth and declining birth rates, contributes to the demand weakness.

9.2.1.3 Trade

While FAO (2003c) indicates that total roundwood harvest across the world has increased some 60% since 1961, the constant-dollar value of forest products exported has increased almost twenty-five-fold. (See Table 9.4.) Much of this is due to the increasing proportion of finished and semi-finished products in trade, as opposed to unprocessed logs or chips.

About one quarter of global timber production enters into international trade, according to FAO, and paper alone makes up about 2% of all global trade (IIED 1996). With a total value of around $100 billion in 1991 (FAO 1995), wood products constituted about 3% of total world trade. This trade is growing rapidly, particularly in industrial countries. By 1996–98, import value was estimated at almost $43 billion and export value was $135 billion (WRI 2000a). Five countries—the United States, Germany, Japan, the United Kingdom, and Italy—accounted for more than 50% of international imports in 2000, while Canada, the United States, Sweden, Finland, and Germany accounted for more than half of international exports (FAO 1999).

Much of the total global trade is within regions. Flows between the United States and Canada, between northern and central Europe, and within Southeast Asia dominate world trade (TMFWI 2001). Where these trade patterns have resulted in shifting timber production to more productive regions (as described later), total timber production has increased more rapidly than the area of forest harvested.

9.2.1.4 Employment

In recent decades there has been a decline in the labor inputs required by the forest products industry, where employment has experienced similar declines as many other extractive and manufacturing industries (U.S. Bureau of Labor Statistics 2004).

For example, from 1955 to the mid-1990s, labor productivity in logging in the United States increased an average of 1.45% annually (Perry 1999). Since output increased at about the same rate, however, employment levels remained relatively steady. Employment in forest product processing has declined in many countries in recent years due to increasing labor productivity. In the United States, for example, over the period 1997–2003 employment in the paper and paperboard production fell by one third while total production barely declined (U.S. Bureau of Labor Statistics 2004).

9.2.1.5 Future Availability

Estimates of future wood demand must be approached with some caution, as past assessments have regularly overestimated needs (Clawson 1979; Sedjo and Lyon 1990). More-recent estimates by FAO (1998b) suggest that the global wood demand by 2045/50 will be about 2 billion cubic meters a year and that supply should

Table 9.4. Forest Product Exports and Imports, 1961–2000 (Data from FAO 2003c)

Region	1961	1980	2000	1961–80	1980–2000
	(million 1996 dollars)			*(percent change)*	
Exports					
Africa tropical	0.2	1	2	590	50
America temperate	2.1	18	45	773	149
America tropical	0.1	1	4	1,214	239
Asia temperate	0.4	4	11	835	177
Asia tropical	0.2	4	10	2,145	113
Europe temperate	3.0	26	67	761	162
Southern temperate	0.1	1	5	2,039	278
Other areas	0.03	1	1	2,235	55
Total	**6**	**57**	**145**	**839**	**156**
Imports					
Africa tropical	–2	0.02	0.4	0.4	1,516
America temperate	258	1.6	8	30	426
America tropical	212	0.2	2	6	989
Asia temperate	0.4	13	33	3,094	152
Asia tropical	0.1	1	6	544	487
Europe temperate	3.7	33	68	776	108
Southern temperate	0.4	2	3	354	114
Other areas	0.4	4	7	1,069	63
Total	**7**	**63**	**153**		

be about the same, with Asia contributing about 700 million cubic meters and North America about 1 billion cubic meters.

Ultimately, the future availability of wood supplies is likely to be related more to growth and productivity of managed and planted forests than to the area of natural forests or gross forest stock. Production from natural forests will continue to be replaced by production from plantation forests, especially in tropical and sub-tropical forests (as described later). The same trend seems likely in many temperate forest areas. In the United States, for example, the harvest of softwood timber on non-plantation native forests is forecast to decline by 25% over the next 50 years, and standing stocks on non-plantation forests are expected to increase significantly (USDA Forest Service 2003).

Although the amount of forest cover is changing differently by region, other factors also contribute to timber supply and availability. (See Chapter 21.) The forest available for timber production has been declining in some parts of the world (in Europe, North America, Taiwan, and Japan, for instance) due to increasing emphasis on non-timber services such as nature conservation and wilderness. For example, some 21 million hectares of productive forestland have been set aside in conservation reserves (parks, wilderness, and so on) in the United States (USDA Forest Service 2001). This area has more than doubled since 1953, reflecting the increased emphasis on non-timber forest values in the latter half of the twentieth century (USDA Forest Service 2001).

In many areas of the world, suburban sprawl and the fragmentation of ownerships are having an effect on the availability of forests for harvesting, management, and recreational access. In addition, the resulting land use patterns create significant problems for land management and wildfire management in the rural-urban interface (Sampson and DeCoster 2000; Gordon et al. 2004). Large areas of land that meet the definition of forest for inventory purposes are not available for timber production due to the small size of the ownerships or reduced access due to isolation from road networks by other ownerships (Tyrrell et al. 2004). Few national forest inventories effectively account for this factor.

In spite of increasing timber harvests, the reclassification of productive forest to non-timber use, and forest fragmentation, the forests available for timber production in Europe and North America have increased in terms of total standing timber stock. In Europe, it is estimated that annual growth in standing timber is around 700 million cubic meters while timber removals in 2000 were around 418 million cubic meters (FAO 2003b). In the United States, softwood sawtimber stocks in 1997 were 8% higher than in 1963, and hardwood sawtimber stocks had nearly doubled (up 95%) in the same period (USDA Forest Service 2001). With both regions tending to reduce harvesting intensity, particularly on publicly owned lands, the prospects for the near future are for continued growth in the standing stock of timber in both Europe and North America.

One potential factor that can deplete these timber stocks in the future is the threat of alien invasive species, which move more freely as a result of increased global trade. For example, recent infestations in central North America by several invasive insects have resulted in the mortality of large numbers of deciduous trees, especially maples and ashes. In the past, such invasives as Dutch elm disease (*Ophiostoma lumi* and *O. novo-ulmi*) have virtually eliminated individual tree species in some areas.

In addition to the volume of standing timber, the quality of the timber resource is also important. For example, North American eastern hardwood forests, while doubling in standing stock in recent decades, are often dominated by species such as red maple (*Acer rubrum*) that are not as valuable for timber as the original forests that were, in many areas, dominated by species such as oaks, hickories, and chestnuts. In many areas of the world, the premium quality trees and most valuable species have been unsustainably harvested, and supplies of those high-value woods are increasingly limited (FAO 2003b).

The uncertainties in this future prospect include political decisions affecting land use and access to the land for timber harvest, changing trade policies, and the uncertain effects of climate change on net forest growth rates. There are indications that the uncertainty of future access to forests for timber harvest is currently discouraging investment in the forest products industry in some regions.

9.2.2 Wood Pulp

Pulpwood is one component of industrial roundwood production, and the production of pulpwood from forest ecosystems is often tightly integrated with the production of other solid wood products. Pulpwood is derived from a variety of wood sources, ranging from the harvest of fast-growing young trees in plantations managed specifically for pulp production, to the small or lower-quality stems removed from managed forests to improve forest quality or health, to the shavings, trimmings, and other wood produced in the manufacture of sawn wood products. Pulpwood accounts for about a third of the roundwood harvested (including fuelwood) (IIED 1996).

In 1995, about 17% of the wood for paper came from primary forests (mostly boreal), 54% from regenerated forest, and 29% from plantations (IIED 1996). This is expected to change as increased output from plantation forests, many of which will mature in the next decade, reaches world markets.

The global production of wood pulp has almost tripled in the past 40 years. (See Table 9.5.) Regional experience is uneven, with the most rapid expansion occurring in the tropical regions, for a variety of reasons described later in the chapter. The rate of expansion has slowed significantly in recent years, and the current global market in pulp and paper products is marked by overcapacity in the industry and low prices. This has resulted in an unprecedented decline in U.S. pulp and paper production and capacity after 1999, for example (*Economist* 2000). Since late 2003, prices for pulp have rebounded, perhaps aided by high demands in the expanding Chinese economy. This current situation does not, however, change the outlook for further structural change and regional shifts in these industries, especially with increased production from plantations globally.

These factors suggest that the prospect for the near future is a continued leveling off of wood pulp production, with continued decline of major pulp mills in the mature production areas of Europe, Japan, and North America. Those impacts, if they occur, will not affect all regions similarly. The industry continues to shift both mill locations and wood supply contracts to regions of lower-cost production, such as South America and Asia. Such shifts are also tied to increased demand in Asia, especially China.

The rapid increase in wood pulp production over the past four decades was tied to several trends, such as increased population and literacy, leading to increased consumption of paper and paper products and increased use of packaging and packing materials as trade in manufactured consumer goods has grown. The slowdown of the rate of growth in wood pulp production, however, indicates a maturation of these markets and the impact of competing materials. Nevertheless, the International Institute for Environment and Development (1996) predicts continued increased consumption of paper globally, with most of the increase in Asia.

Even so, there appears to be little evidence to suggest that changes in forest ecosystem condition will materially affect the availability of wood pulp globally in the foreseeable future. In fact, the evidence suggests that the increased harvest of young plantations will continue to keep supplies ample and prices low. Since most of the end products of wood pulp (packaging, paper, and so on) are traded in market economies, it is unlikely that changes in the supply will affect consumer well-being, since these societies are generally less vulnerable to modest price changes, and world trade is active in most of these items.

The use of non-wood fiber in pulp supply is expected to remain low and concentrated in Asia. Non-wood materials made up 5.3% of global pulp in 1983 and 11.7% in 1994, and they are expected to reach 12–15% by 2010 (Pande 1998). Most of the non-wood fiber is used in ''small-scale pulp mills'' (less than 30 tons a day), many of which are currently being closed as a result of poor pollution controls and increasingly stringent standards (e.g., FAO 1998a). This industry has not been well supported by research and development of improved technology or pollution controls (Hunt 2001). Two scenarios are likely for the small-scale non-wood pulp sector. Either most small mills will eventually be replaced by larger regional mills that use wood fiber, or cost-effective pollution abatement will be developed, in which case the projected 10–15% of global production of paper from non-wood fibers may be realized.

9.2.3 Craft Wood

The use of wood as a basis for local crafts is common in forested and wooded regions. The products range across a wide variety—from musical instruments to special furniture, toys, and fixtures

Table 9.5. Wood Pulp Production, 1961–2000 (Data from FAO 2003c)

Region	1961	1980	2000	1961–80	1980–2000
	(million tons)			*(percent change)*	
Africa tropical	0	0.07	0.04		–41
America temperate	33	66	85	98	28
America tropical	0.5	4	8	673	128
Asia temperate	8	20	22	146	8
Asia tropical	0.05	1	7	1,292	804
Europe temperate	18	31	41	68	33
Southern temperate	1	4	9	253	117
Other areas	0.04	0.3	1	789	74
Total	**62**	**126**	**172**	**104**	**36**

and to artistic and decorative objects. The woods prized for many of these objects are often culled from commercial timber production lines.

While wood crafting is often a significant local economic or cultural activity, there are few data to address the importance of these wood products at the ecosystem, country, or regional level, and few reliable data at the global level to assess the condition and trends of the production of craft wood products. From the limited information available, Bali exports about $100 million of wood carvings a year, suggesting an important contribution to local economies. A study done by CIFOR (2002) indicated that the African craft wood industry is not sustainable, with a declining availability of preferred tree species in most African countries.

9.2.4 Carbon Sequestration in Wood Products

The international community has increased its focus on the issue of climate change due to the buildup of atmospheric carbon dioxide and other greenhouse gases. One topic receiving significant attention has been the ability of forests to sequester atmospheric CO_2 in the process of photosynthesis. (See Chapter 21.)

The harvesting of forest products from sustainably managed forests leads to medium-term carbon sequestration in the form of stable wood products that remain in use for decades or centuries (Skog and Nicholson 1998). Functions for quantifying the rate of retirement or turnover of a wide variety of forest products have been developed, allowing analysts to calculate the carbon fate of harvested wood products (Skog and Nicholson 1998).

At this time, there have been no carbon offset payments or credits recognized for wood product storage, and the national reporting guidelines under the United Nations Framework Convention on Climate Change have treated wood products as though the carbon contained was released in the same year that it was harvested (Houghton et al. 1997). This would be a reasonable assumption if the amount of wood products in use were stable, but it has been estimated that the total amount of wood stored in products was increasing globally at a rate equivalent to about 139 million tons of carbon per year in 1990 (Winjum et al. 1998). Continuing research and international negotiations are seeking practical ways in which this carbon sequestration can be appropriately documented and credited to countries under the UNFCCC and the Kyoto Protocol.

9.2.5 Drivers of Change in Production and Consumption of Timber Products

Increased production of wood products is associated with the growth in human population, improved literacy, increased industrial development, and the associated greater demand. Most of predicted future human population growth is expected to occur in developing countries and to place more demands on forest resources.

Nevertheless, as noted earlier, there are many factors affecting use of wood products that have resulted in reduced demand for some products, with changes in structural products and recycling; at the same time, other factors are leading to increased consumption, including increased literacy and the development of the Chinese economy. Still other factors are influencing how products are produced, where supplies come from, and which nations are importers and exporters of wood products. Aside from production and demand factors, climate change will have an impact on the forests of many nations in the future and will likely result in the increased use of plantations to sequester carbon to mitigate change (Gitay et al. 2001). In spite of difficulty in quantifying clear cause-and-effect relationships, some causal factors can be identified and assessed, at least in a general manner. These are discussed briefly in this section. (See also MA *Scenarios,* Chapter 7.)

9.2.5.1 Globalization

The trend toward globalization of timber trade has significantly affected the forest products industries in recent decades. As markets become more globalized, companies tend to rely more on plantation forests than on natural ones, particularly in the southern temperate and Asian countries, where labor and materials tend to cost less. Technological advances have helped to enable long-distance operations. Information and communications technologies allow companies and traders to manage activities and processes across the world. Falling transportation costs, spurred in part by increased trade in manufactured commodities, help lower shipping costs for relatively low-value material, such as wood chips or other unprocessed fibers.

Market competition encourages firms to relocate production facilities or to buy production inputs in regions where lower labor costs, easier access to resources, higher timber yields, good governance, political stability, functioning logistics and service, availability of recycled fiber, or any combination of these factors exist that can bring costs down and increase profits. In 1999, for example, the production costs for bleached pulp in Chile was estimated at $330 per ton, compared with $420 per ton in northern industrial countries (*Financial Times* 1999).

During the 1970s and 1980s, world trade in wood chips emerged as a growing factor in the paper industry. At present a fleet of more than 100 specialized chip vessels operates under charter, hauling chips long distances. Increasingly, chip exports are being based on plantation forests in sub-tropical and tropical regions instead of primary forests or low-value secondary forests in temperate regions.

9.2.5.2 Supply Shifting

Shifting timber production is in part a function of globalization and the lower cost of fiber from plantations in regions of the Southern Hemisphere, but it is also a function of political decisions to protect forests from harvest (Berlik et al. 2002). When affluent regions use more wood products than they produce, the harvest is often shifted to regions that have less capability or desire to enforce oversight on such matters as environmental impact or worker safety and health. The result is greater negative impact than would arise if consumption were reduced, or production increased, in the affluent region (Berlik et al. 2002). Both depletion of supply and shifting technologies also result in changes among the species harvested.

High-quality veneer and sawn wood continue to be produced largely from primary or secondary natural-origin forests as opposed to plantations. A major exception is the management of plantations in northern and central Europe on long rotations for high quality sawlogs. Pulkki (1998) suggested that sustainable forest management techniques could ensure the long-term provision of valuable species from most tropical areas as well, but that is not a prospect for the near-term future. Teak offers a particularly good example of a high-quality hardwood species that can be grown to sawlog size in about 30–40 years in tropical areas. Little teak is now derived from natural origin forests (Pandey and Brown 2000), and the future of the species as a commercial product depends on plantations (Rasmussen et al. 2000).

Traditionally valued rare tropical hardwoods have seen shifting patterns of sourcing over the centuries as early supplies were depleted and replacement species emerged, often from other continents. Given the nature of the species, the trends in deforestation, and weak institutional capacity in producing areas, many valuable tropical species will decline markedly in availability in future decades (Adams and Castano 2002).

9.2.5.3 Increase in Plantations

The recent increase in plantations is forecast to continue into the foreseeable future, even if the rate of expansion proceeds more slowly than in the recent past. FAO estimates that the plantation share of roundwood production will grow from the current one third to almost half of total global production by 2040. Roundwood production from plantation forests is likely to provide 906 million cubic meters by 2045 compared with 331 million cubic meters in 1995 (FAO 2000c, 2001a).

There is considerable debate over the appropriate role of plantations in relation to sustainable forest management (UNFF 2003). Oliver (1999) estimates that plantations growing 12.5 cubic meters per hectare per year on 8% of the world's forested lands could satisfy current global wood consumption, easing pressure on natural forests. Others argue that the competition from plantations can render the long-term management of many forests uneconomical, thus increasing the incentives to exploit and abandon them or to sell them off for development or other land uses (TMFWI 2001). Investments in plantation forestry will only be made under good governance (Rice et al. 1997). Most plantation investment is in countries with stable political systems, high availability of land, and climate and soil conditions that promote high yields. Whether that concentration can continue for long without controversy over conflict with other land uses, traditional users, or environmental impact is highly uncertain (Durst and Brown 2002).

In the near future, the production from plantations will significantly increase due to the age structure of the current plantations. In 1995, it was estimated that some 55 million hectares of plantations were younger than 15, and some 22 million hectares were in the 0–5 year age class (Brown 2000). Many of those plantations will be coming into harvest age between 2005 and 2010, and to the extent that they reflect the enhanced yields being pursued through improved varieties, fertilization, and other management improvements, their impact on markets will be significant.

There is a large body of research available to enable plantation managers to improve yields from their lands by selecting specific stock or improved stock from various genetic improvements, depending on species. For example, Newton (2003) suggested that volumes in planted northern conifers can be improved by 7–26% at rotation age through genetic improvement, Matziris (2000) suggested an observed volume increase of 8–13% in Aleppo pine (*Pinus halepensis*) in Greece, and Li et al. (2000) estimated volume improvement in loblolly pine of 12–30% through tree improvement.

Planted forests supply less than 7% of wood used for fuels (FAO 2000c), but the opportunities to expand various forms of agroforestry in community settings, reducing travel times to obtain fuelwood and supplying livestock fodder, are immense and could have large impacts on the quality of life in many parts of the world (Sanchez 2002).

9.2.5.4 Mechanization and Utilization Technology

Mechanization of timber harvesting has reduced employment in the forestry sector, particularly in the tasks of felling trees and transporting logs. However, mechanization has been key to improving forest management and has led to reduced injury and mortality in the sector.

The output of forest products has risen faster than the production of industrial roundwood over the last 20 years. Conversion efficiency, recycling, and waste reduction are all contributing factors. In developing countries, however, efficiency is still low and improvements will increase fiber availability (Chen 2001). For example, while mills in the industrial world produce about 70% product from the wood received, mills in the developing world reach only 30% (WWF n.d.). Closing this ''efficiency gap'' through technology transfer and other means offers a significant opportunity for meeting future commodity demands without increasing pressure on forest ecosystems.

Engineered wood products are becoming increasingly common as a result of reductions in the availability of high-quality structural wood, competition from steel products, and cyclical wood prices. These products, derived as a result of new technologies, essentially turn low-quality wood and wood residues into products valuable for construction and furniture (Enters 2001). The use of engineered wood products in the North American market, for example, has grown at a rate of 20% per year since 1992, reaching more than 29 million cubic meters in 1997 and projected to rise to over 45 million cubic meters by 2005 (Taylor 2000). If the use of these technologies continues to spread, the pressure on some ecosystems and high-quality species will be eased.

9.2.5.5 Global Energy Sources and Costs

As nonrenewable fossil energy supplies decline and new sources of renewable energy are sought, the implications for the supply and consumption of forest products are significant. They are not, however, all pressing in one direction, so the potential effect is mixed and difficult to discern at this point.

To the extent that the cost of energy rises in response to fossil supply changes, forest product technologies that are energy-intensive will become less competitive. Whether this will affect some of the new engineered wood products is unclear. In addition, field production methods that rely on mechanization may suffer competitively against those that use more traditional means of growing, harvesting, and processing timber, and trade could be affected if transportation costs rise significantly.

On the other hand, increasing prices for fossil fuels are likely to encourage more-rapid development of biomass-based fuels, and their emergence could provide outlets for low-grade timber products that currently lack markets. On managed natural forests, in particular, the sale of low-grade timber could provide the financial support needed to invest in thinning, weeding, and other management practices that result in improved forest health and the production of higher-quality timber products. Such markets could also provide economic incentives for the establishment of agriculture or forest plantations devoted to woody crops grown specifically for energy production.

9.2.5.6 Sustainable Forest Management

Appropriate forest management can improve yields and permit long-term sustainable timber production from extensively managed forests. However, managing forests in a sustainable manner may create short-term reductions in timber harvest as managers seek to replace production goals with sustainability goals. (See Chapter 21.)

Although there are still significant differences in the national interpretations of sustainable forest management progress, FAO reports that in 2000 some 89% of forests in industrial countries were subject to a formal or informal management plan (FAO 2001a). Although reports from developing countries were less complete, about 6% of those forests were reported to be subject to a formal management plan covering at least five years. These efforts may be too new to assess the ultimate impact on timber harvest levels, and there is no international assessment of their effect at this time.

There is a clear efficiency gap in logging methods between forests in many tropical and sub-tropical areas and sustainably managed forests elsewhere. The result is considerable waste of wood, loss of forests, forest degradation, and soil damage in unsustainable operations. The Tropical Forest Foundation suggests that 50% less stem damage during operations would increase productivity on a given land base by 20%. The application of sustainable management practices in developing countries (that is, reduced impact logging) would go a long way toward improving long-term fiber yields and the effective and efficient use of extracted resources, while conserving forests as systems (FAO 2003b). Improved infrastructure, reduced corruption, and independent certification may all be required for improved forest management to become a reality in many developing nations.

9.2.5.7 Forest Certification

Forest certification has been developed as a means of helping demonstrate that specific forests are being managed in a sustainable manner under a defined set of standards as wood products are harvested (see MA *Policy Responses,* Chapter 8). It is described by proponents as a market-based instrument, with the implicit assumption that consumers will prefer certified forest products and be willing to pay a price premium sufficient to cover the cost of the certification process and the associated management techniques. Timber producers that have adopted certification have done so primarily to reduce pressure from environmental NGOs and to satisfy customers such as merchants and retailers who are at risk from NGO campaigning.

By 2000, several certification schemes had emerged, and some 80.7 million hectares, or about 2%, of the global forest area was certified (FAO 2001a). Virtually all of this land (92%) was in the industrial regions of North America and Europe. The movement has continued to expand rapidly, and by 2003 some 124.1 million hectares were reported certified on the Web sites of three large certification systems—the Programme for Endorsement of Forest Certification Schemes (formerly the Pan-European Forest Council), the Forest Stewardship Council, and the Sustainable Forestry Initiative—and the Canadian Standards Association added another 14.4 million hectares. By 2004, the estimate of certified forests in those four systems had grown to 164 million hectares (van Kooten et al. 2004). However, certification is still largely a phenomenon of industrial countries.

The implications of certification for the future production of timber remain uncertain. The costs of achieving certification are significant, and the extent to which those costs might create competitive imbalances is still uncertain. The hope that certified products would command a price premium that could cover the additional costs has not yet been realized, and it seems unlikely in the foreseeable future. It is possible that market pressures (particularly access to specialized markets in regions such as Europe) could create new and significant pressures for companies to undergo certification.

9.2.5.8 Deforestation

Deforestation and the loss of forests reduces the land's capacity to produce wood and other services. (See Chapter 21.) Loss of forests has a long history throughout Europe and western Asia, but during the last four decades the highest deforestation rates have been in tropical forests in Africa, Southeast Asia, and South America, where it is currently estimated that over 100,000 square kilometers per year are deforested (FAO 2001a).

Where deforestation continues in tropical forest regions, producers may be unable to maintain past production levels because forests are converted to other land uses or lands become too degraded to recover to forests. One example is in Africa, where producers in Ghana and Côte d'Ivoire are losing forest to large-scale conversion to coffee and cocoa plantations (TMFWI 2001). Certain forest types, particularly dry tropical forests, are especially subject to land use change.

9.2.5.9 Political and Economic Change

Political and economic changes occur regularly, and most create largely local or regional impacts on the production or consumption of timber products. Some, however, such as the collapse of the Soviet Union, the decision to eliminate timber harvest in major areas of China, or increased corruption (Smith et al. 2003) create impacts on the forest products industry around the globe. Given the increasing trend toward globalization and supply shifting described earlier, political decisions that once created mainly local or national impacts may now affect global supply and demand dynamics.

One dynamic that exists but is difficult to assess is the uncertainty associated with public policy. Investors who fear that public pressure will reduce access to timber supplies, or force new costs on production processes, may hesitate to make investments or may move their operations to locations perceived to be less risky. This raises the specter of extractive industries concentrating on the least restrictive areas, where public pressures for effective pollution controls or sustainable management are lower and the resulting environmental and social impacts are higher.

9.2.6 Environmental and Social Impacts of Timber Extraction

9.2.6.1 Environmental Impacts

Poorly planned or excessive timber harvesting can increase road access into remote forest areas, leading to a reduction in forest interior and increasing the "edge" effects associated with forest fragmentation (Kremsater and Bunnell 1999). This has resulted in wildlife population declines and reduced species richness (FWI/GFW 2002). Increased access to forests promotes illegal logging as well as poaching of wildlife resources and hunting of bushmeat. The trade in illicit bushmeat has become so widespread that in 2002 the signatories to the Convention of Biodiversity adopted a resolution and a program of action to deal with this issue at their Sixth Convention of the Parties, and the Convention on International Trade in Endangered Species of Wild Fauna and Flora has established a special working group to deal with this issue.

Environmental concerns over single-species plantation forests compared with managed natural forests include reduced biodiversity, degradation of soils, reduced water conservation, increased susceptibility to pest invasion, and impacts of genetic modifications on natural gene diversity (Nambiar and Brown 1997; Estades and Temple 1999; Lindenmayer and Franklin 2002; Thompson et al. 2002; Cossalter and Pye-Smith 2003; SCBD 2003). However, under many situations, when plantations are established on degraded lands and are appropriately managed they can increase local biodiversity through re-establishment of native species in the understory (Lugo et al. 1993; Allen et al. 1995).

9.2.6.2 Social Impacts

The importance of wood products to domestic industries, employment, building materials, and energy supplies can be estimated by several measures. Wood products facilities at all scales provide employment that can be important to local communities. Harvesting trees, hauling logs and products to market, and handling shipments at ports engage additional workers. In some instances, the cycle of work is dictated by weather, creating seasonal employment, for example in the Amazon region, where the flooding cycle halts logging and milling for months at a time.

FAO estimates that the global forestry sector provides subsistence and wage employment equivalent to 60 million work years, with 80% in developing countries (FAO 1999). Much of this involves people who work in an ''informal'' economy. One estimate is that for every job reported in the official surveys, there could be as many as two jobs that go unreported (TMFWI 2001). In addition, timber products and fuelwood are critical portions of many subsistence economies.

The number of people involved is significant, but the data for evaluation of trends and impacts on human well-being are scarce. For example, European enterprises with fewer than 20 employees are not included in formal employment surveys (EU 1997). Yet in the European Union it is estimated that over 90% of all firms have fewer than 20 employees (Hazley 2000). One database lists 7,000 Indian workers in furniture making, when it seems more likely that there could be several hundred thousand thus employed in this country of 1 billion people (TMFWI 2001). The FAO estimate of 60 million work years is likely to be an underestimate of the true figure.

The impacts of economic change and development strategies fall unevenly on different portions of society. Conversion of forests into timber production as a primary objective may reduce access and availability for non-timber resources and values, often at the expense of indigenous populations that were unable to profit from the increased industrial output. In many developing countries, forests are a primary source of energy, food, and medicine for some segments of society—often the poor. Forest sources of food are often most critical as buffer supplies to help subsistence societies through periods of crop shortages or seasonal famines, and medicines derived from forest plants are used by some three quarters of the world's people, with thousands of medicinal plants identified as important sources, particularly in tropical forest ecosystems. Where forests are converted to intensive timber production or plantations, the resulting loss of biological diversity is mainly of these non-timber species, with a resulting decline in well-being for the people dependent on them.

Public policy decisions that alter timber harvests also have important impacts on people. It is estimated that China's decision to restrict timber harvest due to concerns for the flooding caused by improper harvesting methods will reduce employment by up to 1 million jobs (*China Green Times* 2000). This is now having major impacts on regional wood markets as Chinese industry turns to international sources for logs and fiber.

Replacement of managed natural forests by plantations at large scales may affect local and indigenous communities, either through displacement or through the loss of the natural forest biodiversity that formerly provided sources of food, medicine, fuelwood, fodder, and small timber on which these communities depend for their livelihoods.

9.3 Non-wood Forest Products

A great number of non-wood forest products are of importance to people in virtually every forest ecosystem and elsewhere. These products contribute directly to the livelihoods of an estimated 400 million people worldwide and indirectly to those of more than a billion. They include foods, medicinal products, dyes, minerals, latex, and ornamentals among others. This section, however, considers only those that are fiber-based and serve as inputs to construction or craft purposes.

9.3.1 Bamboos

There are approximately 1,200 species of woody and herbaceous bamboos, the former being most important from the socioeconomic perspective (Grass Phylogeny Working Group 2001). Many woody bamboos grow quickly and are highly productive. For example, the shoots of *Bambusa tulda* elongate at an average rate of 70 centimeters per day (Dransfield and Widjaja 1995). Annual productivity values range between 10 and 20 tons per hectare per year, and bamboo stands may achieve a total standing biomass that is comparable to some tree crops (of the order of 20–150 tons per hectare) (Hunter and Junqi 2002). It is estimated that bamboo makes up about 20–25% of the terrestrial biomass in the tropics and sub-tropics (Bansal and Zoolagud 2002). A substantial amount of bamboo timber comes from plantations, although natural forests are also important.

Bamboos are multipurpose crops, with more than 1,500 documented uses. As a construction material, bamboo is widely used in all parts of the world where it grows, and because of its high strength-weight ratio, bamboo is the scaffolding material of choice across much of Asia. The tubular structure of the plant is optimally ''engineered'' for strength at minimum weight. In many places, its use is restricted almost exclusively for low-cost housing, usually built by the owners themselves. For this and other reasons, bamboo is often regarded as the ''poor man's timber'' and used as a temporary solution to be replaced as soon as improved economic conditions allow. However, architects' interest in working with bamboo has also led to this becoming a common building material for the wealthy. Modern manufacturing techniques allow the use of bamboo in timber-based industries to produce flooring, board products, laminates and furniture.

Despite its importance, very little is known about the worldwide distribution and resources of bamboo, especially in natural forests, although some preliminary regional assessments are available (Bystriakova et al. 2003, 2004). As a non-wood forest product, and one that is often harvested in non-forest settings, bamboo is not routinely included in forest inventories. According to FAO, statistical data on bamboo timber are only available for 1954 to 1971 (FAO 2001a). Today, very few countries monitor non-wood forest product supply and use at the national level, although program efforts in some countries (such as India) are beginning to occur.

Although reported figures on the area of bamboo forests are inconsistent, it is widely accepted that China is the richest country in the world in terms of bamboo resources. China's bamboo forests cover an estimated area of 44,000 to 70,000 square kilometers, mostly of *Phyllostachys* and *Dendrocalamus* species. Their standing biomass is estimated at more than 96 million tons (Feng 2001). Asia ranks first in bamboo production, and Latin America is second. It is estimated that bamboo in Latin America covers close to 110,000 square kilometers (Londoño 2001).

Worldwide, domestic trade and subsistence use of bamboo are estimated to be worth \$8–14 billion per year. Global export of bamboo generates another \$2.7 billion (INBAR 1999). Bamboo is increasingly being used as a substitute for wood in pulp and paper manufacturing, and currently India uses about 3 million tons of bamboo per year in pulp manufacture and China about 1 million tons, although China is set to increase the use of bamboo for paper to a target of 5 million tons per year.

In many countries in Asia, Africa, and Central and South America, bamboo products are used domestically and can be very significant in both household and local economies. In parts of Africa, for example, the majority of rural families depend entirely on raw bamboo for construction, household furniture, and fuel. Since the products are traded locally, statistics do not enter the national accounting systems. Thus the real value of bamboo products, as well as the impact of changing supplies on human well-being, is difficult to estimate.

9.3.2 Rattans

Rattan is a scaly, fruited climbing palm that needs tall trees for support. There are around 600 different species of rattan, belonging to 13 genera; the largest of which is *Calamus,* with some 370 species (Sunderland and Dransfield 2000). It is estimated that only 20% of the known rattan species are of any commercial value. The most important product of rattan palms is cane from the stem stripped of leaf sheaths. This stem is solid, strong, and uniform, yet highly flexible. The canes are used either in whole or round form, especially for furniture frames, or split, peeled, or cored for matting and basketry. Rattans require considerable treatment, including boiling and scraping to remove resins and dipping in insecticides and fungicides prior to drying. The range of indigenous uses of rattan canes is vast—from bridges to baskets, fish traps to furniture, crossbow strings to yam ties.

Rattans are almost exclusively harvested from the wild tropical forests of South and Southeast Asia, parts of the South Pacific (particularly Papua New Guinea), and West Africa. Much of the world's stock of rattan grows in over 5 million hectares of forest in Indonesia. Other Southeast Asian countries, such as the Philippines and Laos, have less rattan but have been relatively self-sufficient due to the appropriate size of their processing sector. No rattans grow naturally elsewhere, and even in these locations deforestation can lead to local extinction of rattans due to their dependence on mature forests.

In the last 20 years, the international trade in rattan has undergone rapid expansion. The trade is dominated by Southeast Asia, and by the late 1980s the combined annual value of exports of Indonesia, Philippines, Thailand, and Malaysia had risen to almost $400 million, with Indonesia accounting for 50% of this trade (Sunderland and Dransfield 2000). The net revenues from the sale of rattan goods by Taiwan and Hong Kong, where raw and partially finished products were processed, totaled around $200 million a year by the late 1980s (Sunderland and Dransfield 2000).

Worldwide, over 700 million people trade in or use rattan. Domestic trade and subsistence use of rattan are estimated to be worth $2.5 billion per year. Global exports of rattan generate another $4 billion (INBAR 1999).

9.3.3 Drivers of Change in Bamboo and Rattan Products

9.3.3.1 Increased Trade

Traditionally, bamboo was used domestically and supplies were extracted based on local requirements. Contemporary additional applications of bamboo have propelled it into new domestic and international markets, increasing profits and income for many participants in the sector. Bamboo generates substantial export income for several countries, such as China ($329 million in 1992) and the Philippines ($241 million in 1994) (INBAR 1999).

Indonesia has a clear advantage over other countries, with its overwhelming supply of wild and cultivated rattan (80% of the world's raw material), and rattan contributes about $300 million to Indonesia's foreign exchange and is an important vehicle for rural development. It also raises the value of standing forests, as rattan is the most valuable of the non-wood forest products in the country, earning 90% of total export earnings from such products (INBAR 1999).

Much of Indonesian wild production was diverted from the international market to the domestic market as a ban on export of unprocessed rattan was phased in between 1979 and 1992. Other major rattan products manufacturers, such as the Philippines and China, are augmenting domestically produced supplies with imports from other rattan producers such as Myanmar, Papua New Guinea, and Viet Nam (often based on unsustainable harvesting), along with continued illicit supplies of Indonesian cane.

9.3.3.2 Depletion of Resource Base

Most bamboo-processing countries are facing a shortage of raw material. The causes of this range from overharvesting and conversion of bamboo forestland to settled agriculture or shifting cultivation. Restoring productive agricultural land to bamboo production is often difficult, as is seen in parts of Nepal, where farmers' concerns for food security are more pressing.

In Indonesia, Laos, and the Philippines, parts of the rattan resource base are becoming scarce. In Indonesia, large-diameter rattans are becoming scarce; in Laos, the rate of exploitation from accessible areas is unsustainably high; and the Philippines has recently become a rattan importer (INBAR 1999). In all cases, loss of forest cover is a main contributor to reduced supply of rattans. As a result of limited supplies of rattan in China and the Philippines, wood is now regularly used in place of large-diameter rattan as a main structural element in "rattan" furniture.

9.3.3.3 Biological Cycles

Many species of bamboo flower simultaneously at long intervals, then set seed and die. Where large areas of bamboo forest are involved, these area-wide disturbances are significant. India, for example, is currently experiencing a bamboo flowering that is expected to affect more than 10 million hectares and peak in 2007 (FAO 2004). The impacts are enormous. The amount of dead woody product vastly exceeds harvesting and storage capacity, leading to serious economic losses. Soils unprotected from erosion are damaged before vegetation is re-established, and local employment suffers. The huge influx of seed leads to a population explosion of rats that, when the seed supply is largely eaten, move out to compete with people for food in regional communities. The last flowering cycle in India (1911–12) led to serious famines, and research and policy measures are under way to mitigate the damage of the current flowering cycle (FAO 2004).

9.3.3.4 Plantations

While a few countries, such as China and India, have successfully promoted bamboo plantations, far more struggle with providing the needed technical and financial support. Potentially adverse effects of bamboo monoculture, such as possible depletion of soil, low biodiversity, and loss of genetic diversity, are largely uncertain.

Private-sector cultivation of rattan, from both large and small-scale plantations, has fallen below expectations and failed to respond to local raw material scarcities. The traditional rattan cultivation system in Kalimantan appears to be under threat, with reduced rattan garden establishment and some conversion of existing rattan gardens to other uses owing to low prices for the main cultivated species and new competing land use opportunities (Belcher 1999).

9.3.3.5 Technological Development and Substitution

Industrial use of bamboo has increased dramatically due to new developments in bamboo processing technology. Laminated bamboo board, bamboo mat plywood, bamboo particleboard, bamboo-fiber molds, floorings, and engineered timber (all called ''composites'') from bamboo fiber are currently available for building construction, architecture decorating, and other applications. In the pulp and paper industry, some bamboo species can be substituted for timber.

9.4 Fuel

In 2000, the world used approximately 1.8 billion cubic meters of fuelwood and charcoal (FAO 2003b). Energy use from fuelwood and charcoal accounts for 0.7–1.1 terawatts out of a global total energy use from all sources of 14.6 terawatts (Gonzalez 2001b). Although these statistics combine fuelwood and charcoal, this chapter discusses the two forms separately because of their different environmental and social impacts.

Although they account for less than 7% of world energy use, fuelwood and charcoal provide 40% of energy used in Africa and 10% of energy used in Latin America (WEC 2001), and 80% of the wood used in tropical regions goes to fuelwood and charcoal (Roda 2002). In Africa, 90% of wood use goes to fuelwood and charcoal, the highest of any region in the world (FAO 2003a). On the other hand, fuelwood and charcoal account for only 20% of wood use in temperate regions (Roda 2002).

The International Energy Agency projects that, by 2030, renewable energy sources will provide some 53% of residential energy consumption in developing countries as a whole, compared with 73% in 2000. In that projection, an estimated 2.6 billion people will continue to rely on traditional biomass for cooking and heating, and virtually all of that will be produced and consumed locally (IEA 2002a).

FAO (2001b) analyses since 1970 indicate that as certain regions in Asia and Latin America have industrialized—particularly China and Brazil—people have switched from fuelwood and charcoal to fossil fuels. Consequently, total global fuelwood use seems to have peaked somewhere around 2000, although total global charcoal use continues to rise (Arnold et al. 2003).

In recent projections of global energy use, the IEA indicates that with continuation of present government policies and no major technological breakthroughs, the use of combustible renewables and waste will grow by 1.3% a year, compared with an overall growth in energy use of 1.7% annually over the next decade (IEA 2002a). The projections reflect the conclusion that the growth of combustible renewables and waste will slow as people in developing countries (which presently use about 73% of world renewables) gain more disposable income and switch to using fossil fuels. A counter-trend may, however, result as the cost of fossil fuels rise and people are forced to use less convenient fuels. With the volatility of international oil prices, these trends will be highly irregular and difficult to predict.

9.4.1 Fuelwood

People harvest fuelwood by cutting or coppicing shrubs, by lopping branches off mature trees, or by felling whole trees. In many rural areas, local people prefer fuelwood from shrub species that will regenerate after coppicing (Gonzalez 2001a). Cooking and heating are the major end uses of fuelwood and charcoal. In some developing nations, wood and charcoal are important for commercial applications such as bakeries, street food, brick-making, smoking foods, and curing tobacco and tea, and fuelwood is an important source of income and employment in many rural areas.

Since developing societies tend to shift from wood fuels to other sources for home heating and cooking, the change in fuelwood production and consumption reflects both a change in economic condition and a change in ecosystem impact. Fuelwood is often produced and consumed largely outside the market system, in subsistence societies, and its value to human well-being is therefore not captured in unadjusted national economic statistics, such as GDP.

9.4.1.1 Production and Consumption

FAO provides the most consistently developed estimates over time for the use of fuelwood. (See Table 9.6.) It should be noted, however, that these data were developed from a fairly small sample, and in many countries the historical data were estimated from models based on population change and average consumption rates. These FAO country data have been grouped according to the forest regions established as being reflective of large forest biomes, but care must be taken in inferring that trends in use of fuelwood translate directly into impacts on forest ecosystems. While charcoal is largely produced from forests in the developing world, fuelwood is produced from woody plants wherever they are found on the landscape. Note, for example that the ''other areas'' category in Table 9.6, which reflects production outside the identified major forest areas, represents a significant amount of fuelwood production. To the extent that agroforestry grows in importance, more of these energy resources will be derived from agricultural and grazing systems.

The African tropical forest region experienced a near-doubling (91% increase) in rural population between 1960 and 2000, but recorded fuelwood value per capita declined, although the decline slowed only in the latter two decades. (See Table 9.7.) On the other hand, the Asian tropical region, which also experienced a doubling of rural populations (98% increase) in the period saw per capita fuelwood values decline at a far more rapid rate, particularly since 1980. This indicates that the dependence on wood as a rural energy source disproportionately declined in Asia relative to Africa (and other regions). This may indicate a shift away from wood fuel as Asian rural populations experienced more rapid development during the period. Nevertheless, FAO predicts an increased demand for wood in central and eastern Asia of about 25% by 2010 over the amount used in 1994 (RWEDP 1997).

Using FAO price data and adjusting for inflation to portray a constant-dollar value of fuelwood production, the average value of fuelwood produced per rural person has declined significantly (with the exception of the Southern temperate region) since 1980. While published prices may stem largely from urban economic transactions, rural populations were chosen for this comparison because of the importance of fuelwood to rural societies, particularly poor rural people.

FAO (2003a) projects that total fuelwood use in Africa will increase by 34% to 850 million cubic meters by 2020, but at a rate less than the rate of population growth. Local forest departments throughout Africa have continued to record locally severe problems of overharvesting to provide wood and charcoal for urban areas (Arnold et al. 2003; FAO 2003a). (See Box 9.1.) Declining local availability of fuelwood is also a problem in areas of India, Haiti, the Andes, and Central America, especially near large cities.

9.4.1.2 Future Availability

Although in the 1970s there was increasing concern that the exploding demand on fuelwood resources, driven by population increases,

Table 9.6. Fuelwood Production, 1961–2000 (Data from FAO 2003c)

Region	1961	1980	2000	1961–80	1980–2000
	(million cubic meters)			*(percent change)*	
Africa tropical	157	211	334	34	59
America temperate	48	93	75	92	–19
America tropical	154	192	247	24	29
Asia temperate	238	276	309	16	12
Asia tropical	498	521	513	5	–2
Europe temperate	100	61	57	–39	–7
Southern temperate	16	18	34	12	88
Other areas	113	160	220	42	38
Total	**1,325**	**1,532**	**1,791**	**16**	**17**

Table 9.7. Fuelwood Production Monetary Value Per Rural Person, 1961–2000 (Prices from FAO 2003c; CPI for real dollar adjustment from U. S. Department of Labor)

Region	1961	1980	2000	1961–80	1980–2000
	(2000 dollars per person)			*(percent change)*	
Africa tropical	17	101	60	478	–41
America temperate	48	797	43	1561	–95
America tropical	48	322	49	577	–85
Asia temperate	20	22	11	8	–50
Asia tropical	50	45	15	–9	–66
Europe temperate	27	29	12	7	–58
Southern temperate	67	48	102	–29	115
Other areas	9	39	21	321	–46
	286	**1,402**	**313**	**390**	**–78**

BOX 9.1

Fuelwood Supply Analysis in Southern Africa

A multiscale analysis of fuelwood availability in the Southern Africa region, done as part of the Southern Africa Millennium Assessment, demonstrates a method of identifying localized conditions that would otherwise be masked in a large-scale assessment (Scholes and Biggs 2004). The analysis utilizes a geographic model to compare the local biomass production rate to the local harvest rate. Where harvest exceeds production the stock will inevitably decline, and, despite some regrowth in the depleted area, the zone in which harvesting occurs expands until the effort required to transport the wood or charcoal exceeds its value.

At the scale of the entire Southern Africa region, much more wood is grown than is consumed as fuel (Scholes and Biggs 2004 Fig 7.1). Thus a regional analysis would lead to the conclusion that fuelwood supply is not a problem. A more fine-grained analysis, however, reveals several very clearly defined areas of local insufficiency that indicate unsustainable use:

- Western Kenya, southeast Uganda, Rwanda, and Burundi;
- Southern Malawi;
- the area around Harare in Zimbabwe and Ndola and Lusaka in Zambia;
- Lesotho; and
- locations in the former homelands in South Africa—in KwaZulu, Eastern Cape and Limpopo provinces, and around Gauteng.

SAfMA local studies confirm that fuelwood shortages are experienced at the last two locations, with the exception of the Gauteng spot. The generalized "rural Africa" model that predicts per capita woodfuel use clearly breaks down in this highly urbanized situation where electricity and coal are well established and relatively cheap energy sources. Conversely, SAfMA local studies in the Richtersveld and Gorongosa-Marromeu confirm that in areas indicated by the regional model to have a fuelwood sufficiency, this is indeed the case.

Checks with local experts and personal experience in the team confirmed that the fisrt three locations currently experience severe fuelwood deficiencies. Therefore, it seems that the regional-scale assessment correctly identified problem areas at a local scale. The authors attribute this to the fact that the underlying wood production models and fuel demand models are working at a resolution of 5 kilometers, slightly smaller than the typical radius of fuelwood depletion around population concentrations.

would have devastating effects on forest ecosystems, currently available evidence suggests that fuelwood demand has not become a major cause of deforestation (Arnold et al. 2003). There are local situations of concern, such as areas near settlements, where an income can be earned by cutting and carrying wood to buyers, but it appears that fuelwood supply is not important enough in most places, with the possible exception of some regions in Africa, to attract national policy intervention to reduce deforestation. The predicted supply for South and East Asia is well above the projected demand.

Recent estimates developed by FAO indicate that global consumption of fuelwood appears to have peaked in the late 1990s and is now believed to be slowly declining. Global consumption of charcoal appears to have doubled between 1975 and 2000, largely as a result of continuing population shifts toward urban areas (Girard 2002; Arnold et al. 2003). Since the production of charcoal entails a net loss of energy and is highly concentrated in forest areas of the developing world, increased charcoal consumption signals pressure on wood supplies.

9.4.1.3 Impacts on Human Well-being

Fuelwood is the main source of household energy for an estimated 2.6 billion people, and in urban areas of developing countries families may spend 20–30% of their income on wood and charcoal fuels (FAO 1999). In terms of impact on their well-being, the main problem for the ever-increasing number of urban dwellers may be price rather than availability of fuelwood.

In rural villages that rely on hand-gathered wood, local shortages may impose serious time constraints on women, whose task it usually is to collect fuelwood, as well as increased energy use and risk of injury associated with lengthy travel with heavy loads. While it is usually women who search for and carry wood on their heads and backs for rural use, many rural people load animals and carts to transport wood for sale in urban areas. Thus, urban demand translates into local economic opportunities. In areas where the demand exceeds the sustainable supply, this can result in serious impacts on local forests.

The lack of reliable and consistent data limits the ability to assess the impact of fuelwood trends on human well-being. People make fuel choices for a variety of reasons, including convenience, price, and reliability of supplies. For example, it has been found that price, availability, and ease of use are very important in affecting fuel choice among urban people, while the price of stoves and the level of pollution from the fuel did not seem to matter as much (Gupta and Kohlin 2003).

A 1996 survey of rural energy in six Indian states found that wood was becoming more scarce and difficult to obtain (ESMAP 2000). As a result, some poorer households were using less efficient fuels like straw and dung, while wealthier households were shifting up the "energy ladder" to purchase charcoal or fossil fuels. The most common response, however, was for households to increase their collection time to compensate for reduced availability and access (Arnold et al. 2003). This and other studies reinforce the conclusion that, in many rural areas, gathered supplies of fuelwood still constitute the main source of domestic energy, making these users more vulnerable to changes that affect their ability to get wood supplies. Reduced access may arise from resource shortages, from changes in land tenure (such as increased privatization), or increased distance to common property. In all circumstances, the result is a reduction in well-being for affected families.

FAO (2000a) estimates that about half the world's households cook daily with biomass fuels and that most of this cooking is done indoors with unvented stoves. Pollutants found in biomass smoke include suspended particulates, carbon monoxide, nitrogen oxides, formaldehyde, and hundreds of other organic compounds such as polyaromatic hydrocarbons. In many parts of the world, for all or part of the year these pollutants are released from stoves in poorly ventilated kitchens and homes. Women, infants, and young children who spend more time in the home suffer the highest exposures.

Several studies have suggested that domestic smoke pollution is responsible for respiratory diseases, low birth weight, and eye problems. The evidence is overwhelming in the case chronic obstructive pulmonary disease in adults and acute respiratory infection in children. There is also evidence to suggest a relationship with perinatal conditions, blindness, tuberculosis, and lung disease. It has been suggested that domestic smoke pollution may also be related to asthma and cardiovascular disease (FAO 2000a), and in total an estimated 1.6 million deaths and 39 million disability-adjusted life years are attributed to indoor smoke, primarily in Africa, Southeast Asia, and the Western Pacific (WHO 2002).

There could be additional impacts in local areas experiencing a shortage of fuelwood. One is the increase in crop residues and dung that are used for cooking and heating in the absence of available wood. These fuels are less efficient and produce more smoke, and the burning of crop residues and dung reduces their availability for enhancing soil structure and fertility, leading to reduced food production. Where adequate fuels are not available, the consumption of cooked food may decline, leading to adverse effects on nutrition and health.

The conclusion to be drawn is that there are important human benefits to be gained from targeted efforts to improve fuelwood availability and accessibility in localities where it is now in short supply. The adoption of improved stoves, with higher efficiency and improved venting, would have important human well-being benefits across wide regions but has often proved more difficult than anticipated, for reasons of affordability and cultural acceptability.

9.4.2 Charcoal

Charcoal consists of the remnants of wood that has been subjected to partially anaerobic pyrolysis (decomposition under heat). Conversion of wood to charcoal creates a product with double the energy per unit mass that is less bulky and more convenient for transport, marketing, and sale than fuelwood. The major domestic end uses of charcoal are cooking and heating, often in the urban areas of developing countries where people are able to purchase, rather than gather, their home energy supplies. Charcoal is not as convenient as petroleum fuels, so as incomes rise people tend to shift from charcoal to coal, gas, or oil. Thus, charcoal consumption has tended to peak, then diminish, as development proceeds. Other large users of charcoal include light industrial users, such as blacksmiths and ceramic and brick makers, and Brazil alone produces approximately 6 million tons of charcoal annually for steel production (WEC 2001).

In Africa, there is a general trend to replace fuelwood with charcoal (Girard 2002). For example, in Bamako, Mali, the proportion of households that use charcoal has risen from nothing in 1975 to 50% in 1996, while the proportion using fuelwood has declined at the same rate (Girard 2002). This trend is expected to continue throughout Africa.

Converting wood to charcoal provides employment and has the advantage of using wood remnants and sawdust that are often otherwise wasted. Nevertheless, much of the charcoal is produced in low-efficiency "cottage industries," resulting in a net loss of energy of as much as two thirds of the energy contained in the original wood, although some of that lost energy is offset by the reduced energy required in transport to markets. Charcoal production, particularly if low-efficiency techniques are used, is a significant source of air pollutants and greenhouse gases.

Charcoal production is declining significantly in Europe and the southern temperate region. (See Table 9.8.) Where charcoal production is increasing to provide fuel for some urban areas, and where inefficient charcoal production methods are common, this may be a local concern for forest sustainability, although there is limited information available to assess these situations (Arnold et al. 2003). Certainly at the regional and global level, trends for charcoal production and use do not suggest broad threats to forest ecosystems.

9.4.3 Industrial Wood Residues

In many modern wood industries, residues that were formerly waste products now provide a portion of the electricity and heating needs of the mill or paper plant. For example, in the mid-1990s, it was estimated that the pulp and paper industry in the United States produced about 56% of its energy needs by burning the unused wood components removed in the pulping process (Klass 1998). In the United States, 98% of the bark, saw dust, and wood trimmings from sawmill operations, and the black liquor produced in the pulping process, are currently used as fuel or to produce other fiber products (Energy Information Administration 1994). Enters (2001) indicates that on average, only half the wood harvested in Asia is used and the rest is unused residue that goes to waste.

As industrial wood processing and paper-making residues have become increasingly used to generate energy, the main impact on local communities has been the associated reductions in air and water pollution. Historically, many mill communities tolerated smoke, chemical aerosols, and degraded stream reaches as a necessary part of maintaining the jobs and economic impact of the mill. Today, the communities that benefit from modern mills have fewer associated pollution burdens.

9.4.4 Biomass Energy

The world currently relies heavily on nonrenewable fossil energy sources such as coal, petroleum, and natural gas, and although long-term forecasts for declining supply of fossil fuels entail a high degree of uncertainty, Klass (1998) estimates that the gradual depletion of oil and natural gas reserves will become a major problem by 2050. As the availability of fossil fuels declines, the only renewable carbon resource large enough to substitute for or replace fossil resources for the production of fuels and electricity is biomass. Policy implications include the opportunity to encourage more efficient and modern biomass systems through technological development and diffusion.

Industrial biomass includes energy systems generating electricity, heat, or liquid fuels from fuelwood, agricultural crops, or manure. In 2000, biomass other than fuelwood and charcoal may have provided 5% of global world energy (WEC 2001). Biogas produced from dung and other carbohydrate-based agriculture products like nonedible oil cake is another major source of energy in Asia, particularly in India and China (Deng 1995).

Current technologies for converting biomass into electricity and fuels include thermochemical and microbial processes such as combustion, gasification, liquefaction, and fermentation (Klass 2002). Biogas is most commonly produced using animal manure, mixed with water, stirred and warmed inside air-tight digesters that range in size from around 1 cubic meter for a small household unit to as large as 2,000 cubic meters for a commercial installation (Ramage and Scurlock 1996). The biogas can be burned directly for cooking and space heating or used as fuel in internal combustion engines to generate electricity.

Examples of thermochemical processes include wood-fueled power plants in which wood and woody wastes are combusted to produce steam that is passed through a turbine to produce electricity; the gasification of rice hulls by partial oxidation to yield fuel gas, which drives a gas turbine to generate electricity; and the refining of organic oils to produce diesel fuels. Another example is the alcoholic fermentation of corn to produce ethanol, which is then used in a variety of formulations in motor fuels (Klass 2002).

Soybeans and oil palms produce oil crops that can be processed directly into biodiesel. The combination of different biomass sources and conversion technologies can produce all the fuels and chemicals currently manufactured from fossil fuels. The major obstacle is the price competition from fossil fuels. While most analysts foresee the economic gap narrowing and reversing as fossil fuel prices rise in response to dwindling supplies, there are varying opinions as to when this may have a significant effect, with estimations up to the middle of the twenty-first century (Klass 2003), and some predicting that peak petroleum production may occur well within the first quarter (IEA 2002b).

The data on production of biomass-based liquid fuels and electricity are limited. One major source, the International Energy Agency (IEA 2003), pools estimates for all renewable sources, including energy generated from solar, wind, biomass, geothermal, hydropower and ocean resources, and biofuels and hydrogen derived from renewable resources.

Table 9.8. Charcoal Production 1961–2000 (Data from FAO 2003c)

Region	1961	1980	2000	1961–80	1980–2000
	(million cubic meters)			*(percent change)*	
Africa tropical	2.6	5.6	12.0	114	114
America temperate		0.5	0.9		70
America tropical	6.0	8.7	13.7	45	58
Asia temperate	0.3	0.3	0.5	8	43
Asia tropical	1.6	2.8	3.4	71	25
Europe temperate	0.3	0.4	0.2	24	–39
Southern temperate	0.6	0.6	0.3	4	–48
Other areas	2.9	4.7	8.3	60	76
Total	**14**	**24**	**39**	**64**	**67**

As noted earlier, fuels and electricity can be produced from almost any biomass resource, but commercial production has been limited. A few examples are power and steam production via the combustion of municipal solid wastes, of fuel gas recovered from landfills, and of biogas produced in wastewater treatment plants. Steam and hot water are produced in the gasification of wood and wood wastes to produce fuel gas for use in commercial buildings and the combustion of black liquor in the pulp and paper industry. Liquid fuels for internal combustion engines come from lipids and fuel oxygenates come from fermented grains. In the United States, production of fuel ethanol from corn has been commercialized, but it relies on federal subsidies and policies requiring the use of organic oxygenates in gasoline to reduce pollution in some areas of the country. A major research and development effort is in progress to displace corn with low-cost cellulosic feedstocks such as crop residues and non-merchantable wood produced through fuel reduction projects aimed at reducing the intensity and severity of forest fires (Sampson et al. 2001).

On a energy content basis, existing global standing biomass is estimated to be about 100 times the total annual consumption of coal, oil, and natural gas in the 1990s, and net annual production of biomass is 10 times annual energy consumption (Klass 1998). Incremental new biomass growth on carefully designed sustainable plantations that produce dedicated energy crops could eventually have large potential uses in meeting global energy demands.

There is considerable variation in the estimates of the biomass in agricultural wastes that might be available for energy production. For example, one study estimates that the potential amount of rice straw and husks available for energy might range from about 300 million to 1,900 million tons (Koopmans and Koppejan 1998). The range involves different assumptions about production as well as the extent to which available crop residues will be used for fuel, fodder, fertilizer, fiber, or feedstock. One of the issues in using crop residues for commercial energy production is that their use may depend on storage for prolonged periods after harvest. Also, the scale of biomass electric plants may exceed locally available feedstock supplies.

Taking into account the net primary productivity of the world's ecosystems and conventional energy technology, global biomass could provide energy at a theoretical rate of 9 terawatts (WEC 2001) to 26 terawatts (Holdren 1991), compared with the current rate of global energy use of 15 terawatts (Gonzalez 2001b). Some regional studies show significant supplies available. (See Table 9.9.) Realistic estimates of supply, however, need to be tempered by several factors:

- Much biomass, such as crop residues and logging wastes, are widely dispersed; making their collection for commercial use difficult and costly.
- The removal of organic material from producing crop and forestlands may compromise their ability to sustain productivity. Organic material returns are essential for maintaining soil quality, so only a portion of the waste biomass can be safely removed.
- The environmental impacts of increased biomass energy production, both positive and negative, need to be considered (Sampson et al. 1993).

An increasing role for biofuels in the world energy system would have significant local economic implications. Growing, harvesting, and transporting these fuels could provide new crop and employment opportunities for rural residents.

Because biofuels are produced from renewable sources, their use does not involve a net transfer of carbon dioxide into the atmosphere. As a result, where they replace fossil sources they can be counted as a positive benefit in attempts to address climate change. To the extent that they become a significant force, the benefits accrue across all nations and societies. For example, the use of bagasse in Australia is estimated to reduce net emissions of CO_2 into the atmosphere by 226,000 tons per year (Ramage and Scurlock 1996).

The benefits of clean, renewable energy and fuels are evident, but the slow rate of their growth in relation to the growth in fossil fuel use reflects the difficult obstacles that biofuels face. An integrated, large-scale biomass energy industry has yet to emerge despite the major expenditures made to develop new technologies and scale them from research to production levels. In most of the industrial world, the lack of financing for first-time production facilities, the difficulty in assuring growers of adequate prices and producers of adequate supplies in the absence of market experience, and the lack of an energy infrastructure geared to dispersed, decentralized production facilities have all deterred industrial development of biomass fuel. The competition from fossil fuels has also contributed to the slow growth in biomass-based production of modern fuels, despite the steady advances from research and technological development.

9.4.5 Drivers of Change in the Use of Biomass Fuels

9.4.5.1 Fossil Fuel Availability

The near-term prospects for the future of biomass fuels remain one of slow growth. If fossil fuel prices continue to rise in the coming decades, the longer-term prospects (2030–50) for biofuels look very positive. The combination of drivers, including concern over global climate change, pollution, and fossil fuel depletion, appears poised to drive government policies and market forces toward an increased role for biomass-based modern energy sources.

9.4.5.2 Income and Development Levels

As incomes rise and development proceeds, people tend to shift from low-cost, heavy, or inefficient fuel sources to those that cost more but require less effort to obtain and use. If development efforts succeed in raising incomes and living standards, pressures on local ecosystems for fuelwood will diminish as people move up the energy ladder to other sources.

9.4.5.3 Technology Development and Transfer

Programs that successfully introduce more efficient cooking and heating stoves, modern renewable sources (such as solar, geothermal, and wind), or other energy innovations can reduce pressure on local sources of biomass fuels. The result can be improved human well-being by lowering the time and effort spent gathering fuel, lowering health impacts from smoke, and supporting improved diets.

Increased use of biomass for commercial energy production will require continued major investment in research, development, and technology transfer.

9.4.5.4 Resource Availability

Lack of accessible fuelwood supplies can be an important localized problem with serious impacts, particularly on rural or low-income people. This can be the result of an imbalance between population levels and local biomass production capability, as described in Box 9.1, in the absence of affordable or accessible energy options. Policy options may include efforts to increase local fuel production (through increased agroforestry), introduce technology innovation, or improve fuel transport.

Table 9.9. Consumption and Potential Supply of Biomass Fuels for 16 Asian Countries[a] (RWEDP 1997)

Consumption/Supply	1994 Area (million hectares)	1994 Mass (million tons)	1994 Energy (petajoules)	2010 Area (million hectares)	2010 Mass (million tons)	2010 Energy (petajoules)
Consumption						
Total woodfuels		646	9,688		812	12,173
Potential supply						
Sustainable woodfuel from forestland	416	670	10,047	370	629	9,440
Sustainable woodfuel from agricultural areas	877	601	9,021	971	692	10,381
Sustainable woodfuel from other wooded lands	93	54	810	81	47	708
Waste woodfuels from deforestation	(4)	606	9,083	(3)	438	6,566
Total potentially available woodfuels	1,382	1,931	28,962	1,420	1,806	27,095
50 percent of crop processing residues	877	219	3,458	971	322	5,105
Total potentially available biomass fuels		2,150	32,420		2,128	32,200

[a]Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Lao PDR, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Viet Nam.

9.5 Fiber

9.5.1 Agricultural Plant Fibers

A wide variety of crops are grown for fiber production. Flax, hemp, and jute are generally produced from agricultural systems, while sisal is produced from the fiber contained in the leaves of the *Agave* cactus, which is widely cultivated in tropical and subtropical areas. (See Chapter 22.) Silk is a special case, produced by silkworms fed the leaves of the mulberry tree, grown in an orchard-like culture. The production of all the listed fibers except silk has declined in recent decades. (See Table 9.10.)

Competition from non-cellulosic fibers has increased significantly in recent years. (See Table 9.11.) According to the U.S. Department of Agriculture (whose data varies slightly from that of FAO in Table 9.10), total world fiber production has grown by 63% in the last two decades, while the proportion of natural (cellulosic) fibers has declined from almost two thirds to under one half (USDA-ERS 2003).

9.5.1.1 Cotton

Cotton is the single most important textile fiber in the world, accounting for over 40% of total world fiber production. It is an unusual crop, in that it is an oil crop grown for its fiber, which develops as elongated surface cells on the seedcoat. The cotton seed itself constitutes about 65% of the harvested crop and contains about 17% oil and 24% protein (Gillham et al. 2003).

While some 80 countries around the world produce cotton, China, the United States, India, Pakistan, and the former Soviet Union have dominated global production since 1961, although their relative share of the global total has changed over time. (See Table 9.12.) Over 70% of the world's cotton is produced in the United States (above 30° north latitude), China, the former Soviet Union countries, and southern Europe (Gillham et al. 2003). The water and fertilizer requirements for high yields of cotton under intensive production are high, and it is this that leads to concentrated production in so few regions.

Cotton is produced on both irrigated and rain-fed cropland, and cotton demand has been the basis for major irrigation projects over the past century. In Uzbekistan, for example, major irrigation developments were constructed in the 1940s to convert the region into the primary cotton producer for the Soviet Union (Gillham et al. 2003). The resulting diversion of water, along with the intensive use of agrochemicals, resulted in disastrous environmental deterioration of the Aral Sea. (See Chapter 20.)

Global production of cotton has about doubled in the past 40 years, while the land harvested has stayed virtually the same (FAO 2003c). However, those global totals mask significant shifting of cotton growing. For example, a major area expansion in Pakistan has been offset by large declines in the rest of the world. FAO

Table 9.10. World Production of Selected Agricultural Fibers, 1961–2000 (FAO 2003c)

Item	1961	1980	2000	1961–80	1980–2000
	(thousand tons)			(percent change)	
Flax	697	620	522	–11	–16
Hemp	300	186	50	–38	–73
Jute and jute-like fibers	3,492	3,609	3,037	3	–16
Sisal	763	548	413	–28	–25
Silk, raw and waste production	33	69	107	111	56
Total	**5,284**	**5,032**	**4,129**	**–5**	**–18**

Table 9.11. World Textile Fiber Production, 1980–2000 (USDA-ERS 2003)

Item	1980		1990		2000	
	(thousand tons)	*(percent of year's total)*	*(thousand tons)*	*(percent of year's total)*	*(thousand tons)*	*(percent of year's total)*
Rayon and acetate	3,243	10.6	2,758	7.0	2,216	4.4
Non-cellulosic fibers	10,479	34.2	14,899	37.7	26,137	52.4
Cotton	14,259	46.6	18,969	48.0	19,466	39.0
Wool (clean)	1,693	5.5	1,978	5.0	1,361	2.7
Silk	56	0.2	66	0.2	86	0.2
Flax	630	2.1	712	1.8	591	1.2
Hemp (soft)	258	0.8	165	0.4	57	0.1
Total Fibers	**30,618**	**100.0**	**39,548**	**100.0**	**49,914**	**100.0**

Table 9.12. Annual Production and Area Harvested of Cotton for Selected Countries and Rest of the World, 1961–2000 (FAO 2003c)

Country	1961	1980	2000	1961–80	1980–2000	1961–2000
Production		*(thousand tons)*			*(percent change)*	
China	800	2,707	4,417	238	63	452
India	884	1,292	1,641	46	27	86
Pakistan	324	714	1,825	120	155	463
United States	3,110	2,422	3,742	–22	55	20
Russia/former Sov. Un.	1,528	2,804	1,487	84	–47	–3
Other	2,815	3,966	5,505	41	39	96
Global Total	**9,461**	**13,905**	**18,618**	**47**	**34**	**97**
Area Harvested		*(thousand hectares)*			*(percent change)*	
China	3,868	4,915	4,041	27	–18	4
India	7,719	7,820	8,576	1	10	11
Pakistan	1,396	2,108	2,927	51	39	110
United States	6,327	5,348	5,285	–15	–1	–16
Russia/former Sov. Un.	2,335	3,147	2,545	35	–19	9
Other	10,216	10,981	8,482	7	–23	–17
Global Total	**31,861**	**34,319**	**31,856**	**8**	**–7**	**0**

data show some inconsistency in yields, with China's year 2000 yield of over 1 ton per hectare being significantly higher than the global average.

Although the rate of increase in cotton production has slowed since 1980, further growth in cotton production is set to continue through either additional planting or irrigation or through increased yields from improved varieties, management techniques, or pest protection. The reasons for declining production in some regions vary and include increased competition for available irrigation water, loss of productive soils to salinization, or declining markets and prices due to continued or increased competition from synthetic fibers.

In one major cotton-producing region—Uzbekistan—the area planted to cotton has declined steadily from a peak of 2.1 million hectares in 1987 to a reported 1.44 million hectares in 2000 (FAO 2003c). Since the demise of the Soviet Union, the ability of the region to trade cotton for food has diminished, and the need to become more self-sufficient in food is contributing to the decline in the area devoted to cotton production. In addition, the collapse of the economy contributed to a lack of fertilizer and other inputs due to the shortage of foreign exchange (Gillham et al. 2003).

Cotton plays a major role in the economies of many developing countries. In India, over 60 million people derive income from cotton and textiles. In Pakistan, textiles employ over one third of the industrial labor force, and in Uzbekistan 40% of the workforce relies on cotton (Gillham et al. 2003). In China, an estimated 50 million families grow cotton, illustrating that much of the world's cotton is produced by smallholders relying primarily on family labor. In these situations, the crop competes with food crops for available land, water, time, and energy, and strong markets or government policies that encourage expanded cotton production may create difficulty in meeting food production needs.

One of the major challenges in cotton production is the management of crop pests. The most widely known pest, the cotton bollworm (*Helicoverpa armigera*), causes millions of dollars worth of damage annually. One estimate suggests that India alone suffers over $300 million in annual damages from this pest (www.nri.org/work/bollworm.htm). This has led to major research efforts around the world to develop improved pest management techniques. One approach, genetically modified cotton, is being tested in many regions but has raised significant controversies.

Smallholders face significant competitive disadvantages in growing cotton, lacking the mechanical implements for timely operations, the inputs to raise yields or protect against pests, and the marketing ability to produce commercial amounts for sale. It has been estimated that it would take 75–150 smallholders, averaging a quarter to a half hectare each, to produce 100 bales of cotton—a common amount needed to attract a commercial contract (Gillham et al. 2003). Thus, many of the world's cotton producers need significant technical and marketing support to maintain cotton production as a viable agricultural option.

Significant changes in the supply of agricultural fibers can have an impact on those craftsworkers, artisans, and local producers who rely heavily on one or more of them for their livelihood. Slow gradual changes, which seem far more likely, will not be as disruptive, as they provide time for adaptation. Although changes in the production of cotton in any one region would not appear to have significant impact on the well-being of consumers, due to the extent to which the fiber is traded on world markets, such changes will affect local food supplies due to the competition of cotton production with food production.

While the controversy surrounding genetically modified organisms extends well beyond cotton, this crop is one where the issues are both current and particularly important. Media reports estimate that some 1.5 million hectare of GM cotton were planted in China in 2001 and some 100,000 hectares were grown in India in 2003 after the country approved testing in 2002 (Reuters 2002, 2004). To date, there are no official data on these crop varieties, but their use is growing rapidly, along with the associated controversies.

GM cotton is the result of genetic engineering that introduces genetic material from the Bt (*Bacillus thuringiensis*) organism into the cotton plant. This protein makes the crop more resistant to pests such as the cotton bollworm. Proponents of the technology point to evidence of increased yields and profits to growers, particularly small growers who lack the capital and equipment to control pests effectively. They also argue that the technology reduces the use of pesticides and lowers associated environmental impacts. Critics of the technology assert that early pest resistance is likely to vanish as pests evolve the capability to overcome the new defenses and that there are dangers of releasing genetic material into the environment that may not be subject to natural controls. They also express concerns that farmers may end up using more pesticide rather than less, as the need to control pests other than the target pests becomes more important.

These are issues of great importance to the future of many crops, and an adequate assessment of the technology and its implications is beyond the scope of this chapter. Such an assessment will be increasingly important as the world grapples with the implications of GMO crops, including cotton.

9.5.1.2 Silk

Silk has long been highly prized for the manufacture of fine cloth. It is produced primarily in Asia, where silkworm culture (sericulture) has been under way for centuries. Originally developed in China, silkworms and their host, mulberry trees, have been exported widely around the world. Although commercial sericulture has been tested in many areas of Europe, northern Africa, and the Americas in the past, world production is now heavily centered in China, which accounted for 73% of reported world production in 2000 (FAO 2003c).

Silk production has tripled and the center of production has shifted from Japan to China over the last 40 years. In 1961, Japan produced 57% and China produced 20% of a total world supply of 32 million tons (FAO 2003c). By 2000, China was producing 73% and India was producing 14% of a world supply that had tripled to 110 million tons (FAO 2003c). China's silk production in 2000 (78 million tons) exceeded total world output in 1980 (68 million tons). The movement of silk production from Japan to China over the recent past appears to be linked primarily to lower labor costs in the very labor-intensive production process.

9.5.1.3 Flax, Hemp, Jute, and Sisal

FAO data contain statistics on several of the world's important fiber crops, including flax, hemp, jute and jute-like fibers, and sisal.

Flax is obtained from the stems of several varieties of *Linaceae usitatissimum,* an annual herb that has been cultivated since prehistoric times. The crop has been transported from its native Eurasia to all the temperate zones with cool, damp climates. It is also grown for oilseed production in many parts of the world and was the major source of cloth fiber (linen) until the growth of the cotton industry. Flax fiber cultivation on agricultural land involves dense plantings to prevent the annual plant from branching, then harvesting before maturity.

The total area devoted to flax production has declined from over 2 million hectares in 1961 to less than 450,000 hectares in 2000. The most significant decline was in the former Soviet Union, where the area devoted to flax went from over 1.6 million to about 200,000 hectares. During that same period, the most significant increase in production was reported from China, where production has grown fivefold to some 215,000 tons. In 2000, the three largest flax producers (China, France, and Russia) produced almost two thirds of total global output (FAO 2003c).

Hemp is the common name for *Cannabis sativa,* an annual herb that was native to Asia but is now widespread around the world due to its history of cultivation for bast fiber and drugs. The fiber, taken from the stem, was once widely used to produce various kinds of cordage, paper, cloth, oakum, and other products. Hemp production has declined dramatically since 1961, particularly in the former Soviet Union. In 2000, the two largest producers (China and North Korea) reported over half of total global production (FAO 2003c).

Jute is the common name for the tropical annuals of the genus *Corchorus*. Many species yield fiber, but the primary sources of commercial jute are two species (C. *capsularis* and C. *olitorius*) grown in the Ganges and Brahmaputra valleys of India. Jute is used primarily for coarse fabrics used in burlap, twine, and insulation. Total world production of these fibers declined between 1980 and 2000, particularly in China, Thailand, and Myanmar, and jute and jute-like fibers are now produced almost entirely in India and Bangladesh, where some 89% of total global production originated in 2000 (FAO 2003c).

Sisal is extracted from the leaves of the Agave cactus *(Agave sisalana* and *A. fourcroyides*), which is widely grown in dry tropical regions. The fibers are strong and used primarily for cordage, such as binding twine for hay bales. Over 70% of the sisal fiber production in 2000 was in Brazil and Mexico (FAO 2003c). The major decline between 1961 and 2000 was reported by Tanzania, where production fell from 200,000 to 20,000 tons in that period (FAO 2003c).

Fibers from *Musa* (banana and abaca), *Ciba, Patendra,* and *Bomba* species and coir from coconut palm are also used in many countries for local crafts, cloth, and other uses.

9.5.2 Wood Fibers

Fibers made of almost pure cellulose derived from wood pulp have been manufactured since the late 1800s. Rayon, the most widely known, was developed in France in the 1890s and was originally called ''artificial silk'' (Smith 2002). It has been commercially produced in the United States since 1910 (Fibersource 2004). In rayon production, purified cellulose is chemically converted into a soluble compound that is then passed through a ''spinneret'' to form soft filaments that are chemically treated or ''regenerated'' back into almost pure cellulose. The fibers are then used to produce cloth, cord, or other products. High-performance cords, such as those used in tires, were developed in the 1940s (Fibersource 2004).

At one time, rayon and cotton competed for similar end uses, but cotton's lower price gives it a competitive advantage. Rayon is moisture-absorbent, breathable, and easily dyed for use in clothing. It has moderate resistance to acids and alkalis and is generally not damaged by bleaches. As a cellulosic fiber, rayon will burn, but flame-retardant finishes can be applied. It is now manufactured primarily in Europe and Japan (Smith 2002), although production has declined almost 50% since 1980.

Lyocell is a more recently developed cellulosic fiber, which entered the consumer market in 1991 and was designated as a separate fiber group from rayon due to its unique properties and production processes. Lyocell is both biodegradable and recyclable, and virtually all of the chemicals used in production are reclaimed, making it a very environmentally friendly fiber (Smith 1999). Lyocell is stronger than cotton or linen both when dry and wet. These characteristics make it highly useful for a variety of clothing and similar uses. Since it is a manufactured fiber, the diameter and length of the fibers can be varied according to the desired end use, allowing the fiber to be substituted (or blended) for cotton- or silk-like appearances (Smith 1999). Industrial uses for lyocell include conveyor belts (due to its strength), cigarette filters, printers blankets, abrasive backings, carbon shields, specialty papers, and medical dressings (Smith 1999).

9.5.3 Animal Fibers

9.5.3.1 Domestic Animals

Animal skins and fibers such as wool and mohair are a staple in many societies' clothing and shelter. Most domesticated livestock provide multiple products such as milk, meat, and fiber. Ranching and herding occur largely in agricultural and dryland systems, and excessive grazing pressure is often cited as a driving force for degradation of those systems. As competition from synthetic fabrics has reduced the demand for wool in recent decades, wool production declined 16% between 1980 and 2000, after rising between 1960 and 1980. (See Table 9.13.) The number of live sheep declined 4.4% in that same period, but since the available FAO (2003c) data list all live animals together and do not differentiate those from which wool is harvested, the decline in wool animals is not clear.

The increase in hide production appears to reflect both increased population (associated with increased consumption of leather goods) and the growth of animal agriculture. FAO (2003c) reports, for example, that the world population of live goats more than doubled between 1961 and 2000.

Skins and hides from domestic livestock are generally produced as a by-product of animals slaughtered for meat, so the trends in Table 9.13 are a reflection of the growth in animal agriculture, as well as increased demand. Wool production has stayed virtually unchanged over the last four decades, showing only a slight decline between 1961 and 2000. This appears to reflect the rough balance between increasing populations and reduced per capita wool usage as other fibers have replaced it in some markets.

9.5.3.2 Wildlife

Skins, furs, wools, and hairs from many species of wild mammals, reptiles, and even birds and fish are traded in the international market to make products ranging from clothing and accessories such as footwear, shawls, and wallets to ornaments and furnishings such as charms, rugs, and trophies. Consumers of these products range from local people in Southeast Asian communities using small pieces of tiger skin as magic amulets to ward off evil and illness, to the world's wealthy, wearing fashionable shahtoosh shawls made from the endangered Tibetan antelope.

The skins, hair, and furs from wild animals have been an important source of clothing and shelter for people throughout human history. In some cases today, this trade is putting further pressure on some of the world's most endangered species. For example, progress made over the years in stemming the demand for tiger bone medicine is being thwarted by what appears to be, in some countries, increased poaching of tigers for their skins. Despite their legal protection, the estimated illegal harvest of tens of thousands of Tibetan antelope annually for their wool has reduced populations to fewer than 75,000 animals, compared with an estimated 1 million at the beginning of the twentieth century. (See Box 9.2.)

For some species, the trade and use of skins and furs can be made sustainable. The revival of crocodilian populations in the wild is considered one of the great conservation success stories of the last quarter-century, demonstrating the effectiveness of the Convention on Trade of Endangered Species and sustainable use management programs. In 1969, all 23 species of crocodilians were threatened or had declining populations. Today, one third

BOX 9.2

Shahtoosh

The wool of the Tibetan Antelope (*Chiru Pantholops hodgsonii*), known as shahtoosh, is a valuable and widely traded commodity, despite the animal's protected status and a 23-year-old international trade ban. Unfortunately, the wool is not collected by combing or brushing the animal but by killing it, so that individual hairs can be plucked from the skin (www.traffic.org/25/wild4_3.htm).

Known as Chiru in its home range on the remote Qinghai-Tibetan Plateau of China, the Tibetan antelope lives at altitudes between 3,700 and 5,500 meters, with some animals venturing into the Ladakh region of India. More closely related to sheep and goats than to other antelope species, Tibetan antelope have developed a super-fine layer of hair to protect against the harsh plateau environment. IUCN classifies the Tibetan antelope as vulnerable to extinction.

Because items made from shahtoosh bring extraordinarily high prices, there is widespread poaching and smuggling of hides and wool. The harsh, remote region and the existence of well-armed and organized poaching gangs make law enforcement difficult and dangerous.

Table 9.13. World Production of Hides, Skins, and Greasy Wool, 1961–2000 (FAO 2003c)

Item	1961	1980	2000	1961–80	1980–2000
	(thousand tons)			*(percent change)*	
Cattle hides, fresh	4,070	5,655	7,389	39	31
Buffalo hides, fresh	322	488	811	52	66
Goat skins, fresh	261	390	840	49	115
Sheepskins, fresh	929	1,106	1,598	19	45
Total	**5,582**	**7,639**	**10,638**	**37**	**39**
Greasy wool	2,619	2,794	2,346		

of crocodilians can sustain a regulated commercial harvest and only four species are critically endangered.

The most likely cause of changes in wildlife-derived skins and fibers will be the ability of governments to control the poaching and trade in the skins and fibers from animals threatened with extinction. Where successful conservation efforts can result in a sustainably harvested supply, production will be maintained. Demand for particular animal products (and the resulting prices) may, in some instances, be driven more by fashion trends or cultural demands than by ecosystem conditions.

9.6 Sustainability of Timber, Fuel, and Fiber Services

While there are local and regional exceptions, the global production and consumption of most timber, fuel, and fiber goods over the last four decades has increased significantly, although the rate of increase has slowed during the past decade. In the process, the continents have become more interconnected through international trade, the value of which has grown much faster than global wood products output.

The impacts on forest ecosystems due to this increased production are difficult to generalize. In some cases, timber harvesting has directly contributed to degrading and deforesting forest ecosystems, most recently in tropical areas. This is particularly true where institutional controls are weak and where destructive and often illegal logging practices are common. In other situations, where modern forest technologies and effective governance occur, forest area and measures of condition are holding steady or improving in the face of increased production. While many negative impacts can be seen immediately, the full impacts on forests (either positive or negative) from particular harvesting practices may not be evident for many years.

For the near future, total global wood supplies are predicted to remain adequate for most market demands, if not in surplus. Increases in demand for forest products in the near future are likely to be met by increases in supply and are unlikely to create significant price increases that would create hardship on consumers. That does not apply to premium species or the high-quality woods that have been overharvested in the past. For the near future, those will be in short supply and will need to be replaced by other species or manufactured products or substitutes.

Fuelwood is a special case, largely because it is so important to the people who depend on it for heating and cooking. It is produced, harvested, and consumed locally in the regions where it is a critical factor in family well-being. Local assessments of fuelwood and its relationship to both ecosystems and communities are feasible and needed, as national or regional assessments of overall fuelwood adequacy mask critical community shortages.

In most parts of the world, changes in the production of the timber, fuel, and fiber in the near future (10–15 years) will be caused primarily by political, social, and economic forces rather than changes in the capacity of ecosystems to produce these services. Exceptions may be the capacity of local ecosystems to meet fuelwood demands in some rural subsistence economies, particularly in Africa, and the reduction in availability of some wildlife skins and fibers due to population declines. Where institutional capacity is weak, significant increases in industrial production of wood or fibers such as cotton can cause adverse impacts on local environments or disadvantage traditional users who relied on the ecosystem for food, shelter, medicines, or other nonindustrial products.

Due to increasing globalization of investments and trade, some of the more important policy impacts on the supply of forest products may come in the form of trade or transportation policies; subsidies or taxes for production, transportation, or manufacturing; economic development; or monetary policy. These policies are made outside the forestry and agricultural sectors, often for vastly different reasons of national interest.

The search for a sustainable future involves important challenges in the provision of timber, fuel, and fiber. Some of those challenges include:

- the skillful management of planted and natural forests to supply wood crops, employ local people, and support improvements in literacy, housing, nutrition, and health;
- the application of wise policy decisions that consider industrial production, environmental quality, and local communities and are supported by sufficient governance to achieve their objectives;
- the development and dispersal of science and technology to improve efficiencies in wood and fiber production and use, to protect important biodiversity, watershed, and social values, and to contribute to the alleviation of poverty; and
- reduced pressure on remaining natural forests to provide habitat for wild species and people whose future is threatened by the loss of those forest types.

These challenges include, but go beyond, science, management, technology, and laws. They are fundamental social issues that each society and nation will have to tackle.

In terms of the assessment made in this chapter, as noted earlier, global generalizations tend to mask local dynamics. Since policy is made locally, nationally, and regionally, the need to understand and assess local and regional conditions is a critical precursor to informed policy-making, and it is hoped that the global context illustrated here will contribute to those efforts.

References

Adams, M. and J. Castano, 2002: World timber supply and demand scenario, government interventions, issues and problems, *Proceedings of the International Conference on Timber Plantation Development,* Manila, 7–9 November, FAO, Rome, Italy.

Allen, R.B., K.H. Platt, and S.K. Wiser, 1995: Biodiversity in New Zealand plantations, *New Zealand Forestry,* **39(4),** pp. 26–9.

Arnold, M., G. Köhlin, R. Persson, and G. Shepherd, 2003: Fuelwood revisited: What has changed in the last decade? CIFOR occasional paper no. 39, CIFOR, Jakarta, Indonesia.

Bansal, A.K. and S.S. Zoolagud, 2002: Bamboo composites: Material of the future, *Journal of Bamboo and Rattan,* **1,** pp. 119–30.

Belcher, B., 1999: The bamboo and rattan sectors in Asia: An analysis of production-to consumption systems, INBAR working paper 22, International Network for Bamboo and Ratan, Beijing, China.

Berlik, M.M., D.B. Kittredge, and D.R. Foster, 2002: The illusion of preservation: A global environmental argument for the local production of natural resources, Harvard forest paper no. 26, Harvard University, Petersham, MA, 24 pp.

Brown, C., 2000: The global outlook for future wood supply from forest plantations, Working paper no. GFPOS/WP/03, FAO Forestry Policy and Planning Division, February, FAO, Rome, Italy.

Bystriakova, N., V. Kapos, C. Stapleton, and L. Lysenko, 2003: *Bamboo Biodiversity:* Information for planning, conservation and management in the Asia-Pacific region, United Nations Environmental Program, Nairobi, Kenya/ World Conservation Monitoring Center/INBAR, Beijing, China.

Bystriakova, N., V. Kapos, and L. Lysenko, 2004: *Bamboo* Biodiversity: Africa, Madagascar and the Americas, United Nations Environmental Program, Nairobi, Kenya/ World Conservation Monitoring Center, Cambridge, UK/ INBAR, Beijing, China.

Chen, X., 2001: Wood residues in China, Appendix 1. In: Trash or treasure? Logging and mill residues in Asia and the Pacific, T. Enters (ed.), RAP publication 2001/16, FAO, Bangkok, Thailand.

CIFOR (Center for International Forestry Research), 2002: Planning for woodcarving in the 21st century, InfoBrief April no. 1, CIFOR, Bogota, Indonesia.

Clawson, Marion, 1979: Forests in the long sweep of history, *Science,* **204(4398),** pp. 1168–74.

Contreras-Hermosilla, A., 2002: Law compliance in the forestry sector: an overview, WBI working paper, The World Bank, Washington, DC, 47 pp.

Cossalter, C. and C. Pye-Smith, 2003: *Fast-wood Forestry: Myths and Realities,* CIFOR, Jakarta, Indonesia.

Deng, K., 1995: Renewable energy benefits rural women in China, Chapter 7. In: *Energy as an Instrument of Socio-Economic Development,* J. Goldemberg and T. B. Johansson (eds.), United Nations Development Programme, New York, NY.

Dransfield, S. and E.A.Widjaja (eds), 1995: *Plant Resources of South-East Asia No 7: Bamboos,* Backhuys Publishers, Leiden, The Netherlands.

Durst, P.B., W. Killmann, and C. Brown, 2004: Asia's new woods, *Journal of Forestry,* **102(4),** pp. 46–53.

Durst, P.B. and C. Brown, 2002: Current trends and development of plantation forestry in Asia Pacific countries, *Proceedings of the International Conference on Timber Plantation Development,* Manila, 7–9 November, FAO, Rome, Italy.

Energy Information Administration, 1994: Manufacturing consumption of energy, US Department of Energy report DOE/EIA-0512(91), US Government Printing Office, Washington, DC.

Enters, T., 2001: Trash or treasure? Logging and mill residues in Asia and the Pacific, RAP publication 2001/16, FAO, Bangkok, Thailand.

ESMAP (Energy Sector Management Assistance Programme), 2000: Energy strategies for rural India: Evidence from six states, World Bank document, August, Joint United Nations Development Programme, New York, NY/ World Bank, Washington, DC.

Estades, C.F. and S.A. Temple, 1999: Deciduous-forest bird communities in a fragmented landscape dominated by exotic pine plantation, *Ecological Applications,* **9,** pp. 573–85.

EU (European Union), 1997: *Panorama of EU Industry 1997,* European Commission, Brussels, Belgium.

FAO (Food and Agriculture Organization of the United Nations), 1995: *State of the World's Forests,* FAO, Rome, Italy.

FAO, 1998a: Asia-Pacific forestry sector outlook study: Status, trends and prospects for non-wood and recycled wood in China, Working paper no. APFSOS/WP/35, FAO, Rome, Italy.

FAO, 1998b: Global fibre supply model, FAO, Rome, Italy. Available at http://www.fao.org/DOCREP/006/X0105E/X0105E00.HTM.

FAO, 1999: *State of the World's Forests, 1999*: FAO, Rome, Italy.

FAO, 2000a: Wood energy, climate and health: International expert consultation, Field document no. 58, Regional Wood Energy Development Programme in Asia (GCP/RAS/154/NET), FAO, Bangkok, Thailand.

FAO, 2000b: Forest resources of Europe, CIS, North America, Australia, Japan and New Zealand, Geneva Timber and Forest study papers 17, United Nations, New York, NY/ Geneva, Switzerland.

FAO, 2000c: The global outlook for future wood supply from forest plantations, Working paper no. GFPOS/WP/03, FAO, Rome, Italy.

FAO, 2001a: Global Forest Resources Assessment 2000, FAO forestry paper 140, FAO, Rome, Italy. Available at www.fao.org.

FAO, 2001b: Past trends and future prospects for the utilization of wood for energy, Global Forest Products Outlook Study, FAO, Rome, Italy.

FAO, 2003a: African forests: A view to 2020, In: *Forestry Outlook Study for Africa,* FAO, Rome, Italy.

FAO, 2003b: *State of the World's Forests 2003,* FAO, Rome, Italy.

FAO, 2003c: FAOSTAT statistics database [online], FAO, Rome, Italy. Available at www.fao.org.

FAO, 2004: NWFP digest no. 4–04, FAO Forestry Department, FAO, Rome, Italy.

Feng, Lu, 2001: China's bamboo product trade: Performance and prospects, INBAR working paper no. 33, INBAR, Beijing, China.

Fibersource, 2004: Rayon fiber (viscose) fact sheet. Available at www.fibersource.com/f-tutor/rayon.htm.

FWI/GFW (Forest Watch Indonesia/Global Forest Watch), 2002: *The State of the Forest: Indonesia,* Bogor, Indonesia/ Washington, DC.

Gillham, F.E.M., T.M. Bell, T. Arin, G.A. Mathews, C. Le Rumeur, et al., 2003: Cotton production prospects for the next decade, World Bank technical paper no. 287. Available at http://www.icac.org.

Girard, P., 2002: Charcoal production and use in Africa: What future? *Unasylva,* **53 (211).**

Gitay, H., S. Brown, W. Easterling, B. Jallow, et al., 2001: Ecosystems and their goods and services. In: *Climate Change 2001: Impacts, Adaptation, and Vulnerability,* J. McCarthy, O. Canziani, N. Leary, D. Dokken, and K. White (eds.), Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, pp. 235–342.

Global Witness, 2002: *Branching Out: Zimbabwe's Resource Colonialism in Democratic Republic of Congo,* Global Witness, London, UK.

Gonzalez, P., 2001a: Deserti?cation and a shift of forest species in the West African Sahel, *Climate Research,* **17,** pp. 217–28.

Gonzalez, P., 2001b: Energy use: Human. In: *Encyclopedia of Biodiversity,* S. Levin (ed.), Academic Press, San Diego, CA.

Gordon, J.C., R.N. Sampson, and J.K. Berry, 2004: The challenge of maintaining working forests at the WUI. In: *Forests at the Wildland-Urban Interface: Conservation and Management,* S.W. Vince, M.L. Duryea, E.A. Macie, and L.A. Hermansen (eds.), CRC Press, Boca Raton, FL, pp.15–23.

Grass Phylogeny Working Group, 2001: Phylogeny and subfamilial classification of the grasses (Poaceae), *Annals of the Missouri Botanical Garden,* **88,** pp. 373–457.

Gupta, G. and G. Kohlin, 2003: Preferences in urban domestic fuel demand: The case of Kolkata, India, Environmental Economics Unit, Department of Economics, Goteborg University, Goteborg, Sweden.

Hazley, C., 2000: *Forest-based and related industries of the European Union: Industrial districts, clusters and agglomerations,* ETLA (Elinkleinoelaman Tutkimuslaitos/Research Institute of the Finnish Economy), Helsinki, Finland.

Holdren, J.P., 1991: Population and the energy problem, *Population and Environment,* **12,** pp. 231–55.

Houghton, J.T., L.G., Meira Filho, B. Lim, K. Treaton, I. Mamaty, et al., (eds), 1997: Revised 1996 IPCC guidelines for national greenhouse gas inventories, Intergovernmental Panel on Climate Change. Available at http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Hunt, N., 2001: Review of PIRA non-wood fibre conference. Available at http://www.tappsa.co.za/html/review_of_pira.html.

Hunter, I.R. and W. Junqi, 2002: Bamboo biomass, INBAR working paper no. 36, INBAR, Beijing, China.

IEA (International Energy Agency), 2002a: *World Energy Outlook, 2002,* IEA, Paris, France.

IEA, 2002b: Renewables in global energy supply: An IEA fact sheet, International Energy Agency, November, IEA, Paris. France. Available at www.iea.org.

IEA, 2003: Renewables information: 2003, IEA, Paris, France. Available at www.iea.org.

IIED (International Institute for Environment and Development), 1996: *Towards a Sustainable Paper Path,* World Business Council for Sustainable Development, IIED, London, UK.

INBAR (International Network for Bamboo and Rattan), 1999: Socio-economic issues and constraints in the bamboo and rattan sectors: INBAR's assessment, INBAR working paper no. 23, Beijing, China.

Khan, M.L., S. Menon, and B.S. Bawa, 1997: The effectiveness of the protected area network on biodiversity conservation: A case study in Meghalaya state, *Biodiversity and Conservation,* **6,** pp. 853–68.

Klass, D.L., 1998: *Biomass for Renewable Energy, Fuels, and Chemicals,* Academic Press, San Diego, CA, 651 pp.

Klass, D.L., 2002: An introduction to biomass energy: A renewable resource. Available at http://www.bera1.org/about.html.

Klass, D.L., 2003: A critical assessment of renewable energy usage in the USA, *Energy Policy,* **31(2003),** pp. 353–67.

Koopmans, A. and J. Koppejan, 1998: Agricultural and forest residues: Generation, utilization and availability. In: *Proceedings of the Regional Expert Consultation on Modern Applications of Biomass Energy,* FAO Regional Wood Energy Development Programme in Asia, Report no. 36, FAO, Bangkok, Thailand.

Kremsater, L. and F.L. Bunnell, 1999: Edge effects: Theory, evidence and implications to management of western North American forests. In: *Forest Fragmentation: Wildlife and Management Implications,* J.A. Rochelle, L.A. Lehmann, and J. Wisniewski (eds.), Brill, Leiden, The Netherlands, pp. 117–53.

Li, B.L., S. McKeand, and R. Wier, 2000: Impact of forest genetics on sustainable forestry: Results from two cycles of loblolly pine breeding in the U.S., *Journal of Sustainable Forestry,* **10,** pp. 79–85.

Lindenmayer, D.B. and J.F. Franklin, 2002: *Conserving Forest Diversity: A Comprehensive Multi-scaled Approach,* Island Press, Washington, DC.

Londoño, X., 2001: Evaluation of bamboo resources in Latin America: A summary of the final report of the project 96–8300–01–4, INBAR, Beijing, China.

Lugo, A.E., J.A. Parrotta, and S. Brown, 1993: Loss in species caused by tropical deforestation and their recovery through management, *Ambio,* **22,** pp. 106–9.

Matziris, D.I., 2000: Genetic variation and realized genetic gain from Aleppo pine tree improvement, *Silvae Genetica,* **49,** pp. 5–10.

Nambiar, E.K.S. and A.G. Brown, (eds.), 1997: Management of soil, nutrients and water in tropical plantation forests, ACIAR monograph 43, Canberra, Australia.

Newton, P.F., 2003: Systematic review of yield responses of four North American conifers to forest tree practices, *Forest Ecology and Management,* **172,** pp. 29–51.

Oliver, C.D., 1999: The future of the forest management industry: Highly mechanized plantations and reserves or a knowledge-intensive integrated approach? *Forestry Chronicle,* **75,** pp. 229–45.

Pande, H., 1998: Non-wood fibre and global fibre supply, *Unasylva,* **49,**

Pandey, D. and C. Brown, 2000: Teak: A global overview, *Unasylva,* **51,**

Perry, I.W.H., 1999: Productivity trends in the natural resources *ndustries*: A cross cutting analysis. In: *Productivity in Natural Resource Industries,* R.D. Simpson, (ed.), Resources for the Future, Washington, DC.

Pulkki, R., 1998: Conventional versus environmentally sound harvesting: Impacts on non-coniferous tropical veneer log and sawlog supplies, *Unasylva,* **49.**

Ramage, J. and J. Scurlock, 1996, Biomass. In: *Renewable Energy-power for a Sustainable Future,* G. Boyle (ed.), Oxford University Press, Oxford, UK.

Rasmussen, J.N., A. Kaosa-ard, T.E. Boon, M.C. Diaw, K. Edwards et al., 2000: For whom and what? Principles, criteria and indicators for sustainable forest resources management in Thailand,DFLRI Report 6–2000, Danish Forest and Landscape Research Institute, Hoersholm, Denmark.

Reuters, 2002: China GMO cotton bad for environment: Greenpeace, Reuters News Service, 4 June.

Reuters, 2004: Monsanto-backed survey sees India GMO cotton bonus, Reuters News Service, 26 March.

Rice, R.E., R.E. Gullison, and J.W. Reid, 1997: Can sustainable management save tropical forests, *Scientific American,* **276,** pp. 44–9.

Roda, J.-M., 2002: Le point sur la place des bois tropicaux dans le monde, *Bois et Forêts des Tropiques,* **274,** pp. 79–80.

RWEDP (Regional Wood Energy Development Program in Asia), 1997: Regional study on wood energy today and tomorrow, Publication FD50, RWEDP, Bangkok, Thailand. Available at http://www.rwedp.org/public.html.

Sampson, R.N. and L.A. DeCoster, 2000: Forest fragmentation: Implications for sustainable private forests, *Journal of Forestry,* **98(3),** pp. 4–8.

Sampson, R.N., M.S. Smith, and S.B. Gann, 2001: Western forest health and biomass energy potential: A report to the Oregon Office of Energy, Oregon Office of Energy, Salem, Oregon, 53 pp. Available at http://www.energy.state.or.us/biomass/forest.htm.

Sampson, R. N., L.L. Wright, J.K. Winjum, J.D. Kinsman, J. Benneman, et al., 1993: Biomass management and energy, *Water, Air, and Soil Pollution,* **70(1–4),** pp. 139–59.

Sanchez, P.A., 2002: Soil fertility and hunger in Africa, *Science,* **295(5562),** pp. 2019–20.

SCBD (Secretariat to the Convention of Biological Diversity), 2003: Interlinkages between biodiversity and climate change, SCBD technical series no. 10, SCBD, Montreal, Canada.

Scholes, R.J. and R. Biggs (eds), 2004: *Ecosystem Services in Southern Africa: A Regional Assessment,* The Regional Scale Component of the Southern African Millennium Ecosystem Assessment (SA*f*MA), Council for Scientific and Industrial Research, Pretoria, South Africa. Available at www.millenniumassessment.org.

Sedjo, R., 2004: Transgenic trees: Implications and outcomes of the Plant Protection Act, RFF discussion paper 04–10, Resources for the Future, Washington, DC.

Sedjo, R.A. and K.S. Lyon, 1990: The long-term adequacy of world timber supply, Resources for the Future, Washington, DC.

Sheingauz, A.S. (ed.), 2001: *Forest Complex of Khabarovsk Kray,* RIOTIP, Khabarovsk, Russia, 255 pp. [in Russian]

Skog, K. and G. Nicholson, 1998: Carbon cycling through wood products: The role of wood and paper products in carbon sequestration, *Forest Products Journal,* **48 (7/8),** pp. 75–83.

Smith, J., K. Obidzinski, Subarudi, and I. Suramenggala, 2003: Illegal logging, collusive corruption and fragmented governments in Kalimantan, Indonesia, *International Forestry Review,* **5(3),** pp. 293–302.

Smith, J.A., 2002: Rayon: The multi-faceted fiber, Ohio State University Extension fact sheet HYG-5538–02. Available at http://ohioline.osu.edu/hyg-fact/5000/5538.html.

Smith, J.A., 1999: Lyocell: One fiber, many faces, Ohio State University Extension fact sheet HYG-5572–99. Available at http://ohioline.osu.edu/hyg-fact/5000/5572.html.

Sun, X., E. Katsigiris, and A. White, 2004: Meeting China's demand for forest products: An overview of import trends, rorts of entry, and supplying countries, with emphasis on the Asia—Pacific Region, Forest Trends, Washington, DC/ Center for Chinese Agricultural Policy (CCAP), Beijing, China/ CIFOR, Bogota, Indonesia.

Sunderland, T.C.H., J. Dransfield, J, 2000: Species profiles rattans. In: Rattan: Current research issues and prospects for conservation and sustainable development, Expert Consultation on Rattan Development, Non-Wood Forest Products No. 14, FAO, Rome, Italy.

TERI (Tata Energy Research Institute), 2000: Case studies in joint forest management, TERI Press, New Delhi, India.

Taylor, R.E., 2000: Substitute products to lumber growing rapidly, Press release, Wood Markets Research Inc., Vancouver, BC, Canada.

Thompson, I., G. Patterson, S. Leiner, R. Nasi, C.N. de P. Pola, et al., 2002: Review of the status and trends of, and major threats to, forest biological diversity, Technical Series No. 7, Secretariat of the Convention on Biological Diversity, Montreal, Canada.

TMFWI (Tripartite Meeting on Forestry and Wood Industries), 2001: *Globalization and Sustainability: The Forest and Wood Industries on the Move,* Report for discussion at the tripartite meeting of the social and labour dimensions of the forestry and wood industries on the move, International Labour Organization, Geneva, Switzerland.

Tyrrell, M.L., M.H.P. Hall, and R.N. Sampson, 2004: *Dynamic Models of Land Use Change in the Northeastern USA,* GISF (Global Institute of Sustainable Forestry) research paper 003, Yale University School of Forestry & Environmental Studies/ State University of New York College of Environmental Science and Forestry (SUNY-ESF), 76 pp.

UNFF (United Nations Forum on Forests), 2003: The role of planted forests in sustainable forest management, Report of the expert group meeting, 25–27 March, New Zealand, UNFF, New York, NY. Available at http://www.maf.govt.nz/mafnet/unff-planted-forestry-meeting/report-of-unff-meeting-nz.pdf.

US Bureau of Labor Statistics, 2004: Bureau of Labor Statistics data. Available at www.bls.gov.

USDA-ERS (US Department of Agriculture–Economic Research Service), 2003: *Cotton and Wool Situation Outlook Yearbook* (CWS 2003), USDA-ERS, Washington, DC.

USDA Forest Service, 2001: 1997 RPA final tables. Available at www.fs.fed.us.

USDA Forest Service, 2003: An analysis of the timber situation in the United States: 1952 to 2050, Gen. Tech. Rep. PNW-GTR-560, USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Available at www.fs.fed.us/pnw/pubs/gtr560.

Van Kooten, G.G., H.W. Nelson, and I. Vertinsky, 2004: Certification of sustainable forest management practices, a global perspective on why countries certify, *Forest Policy and Economics*. In press.

WHO (World Health Organization), 2002: *The World Health Report 2002: Reducing the Risks, Promoting Healthy Life,* Geneva, Switzerland, 248 pp.

Williams, M., 2003: *Deforesting the Earth,* University of Chicago Press, Chicago, IL, 689 pp.

Winjum, J.K., S. Brown, and B. Schlamadinger, 1998: Forest harvests and wood products: Sources and sinks of atmospheric carbon dioxide, *Forest Science,* **44(2),** pp. 272–84.

World Energy Council (WEC), 2001: *Survey of Energy Resources,* 19th ed., WEC, London, UK.

WRI (World Resources Institute), 2000a: *A Guide to World Resources 2000–2001: People and Ecosystems: The Fraying Web of Life,* WRI, Washington, DC.

WRI, 2000b: An overview of logging in Cameroon, WRI, Washington, DC.

WWF (World Wide Fund for Nature/World Wildlife Fund), 2000: *Squandering Paradise? The Importance and Vulnerability of the World's Protected Areas,* N. Dudley (ed.), WWF, Gland, Switzerland.

WWF, n.d.: The forest industry in the 21st century. Available at http://www.wwf.de/imperia/md/content/pdf/waelder/nutzungneu/forest_industrie.pdf.