Chapter 2

Importance of Tropical Forests

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HIGHLIGHTS

- The potentially renewable productivity of tropical forests will become increasingly important over the next 30 years as the tropical nations' population grows from 2 billion to 4 billion people.
- Tropical forests support economic development. They sustain production on land that rapidly loses productivity if they are removed and they can restore the productivity of degraded land.
- Economic development in tropical nations is important to the people of the United States for humanitarian reasons and because of our economic ties with these nations.
- Industrial wood and other forest products earn substantial foreign exchange for tropical nations that trade with the United States.
- Tropical forest resources provide food, fuel, medicines, and other basic human needs for millions of people who live in and near them.
- Where fuel wood is not available, agricultural lands are damaged as people have to burn crop residues and manure that would otherwise be used as fertilizer.
- The highly diverse tropical forests contain plants and animals that have great potential value for medicine, agriculture, and other industries. These will be more valuable as industries come to rely more on biotechnology.

SOCIAL AND ECONOMIC CONTEXT

Tropical nations face a dilemma. Forests must be cut and cleared to increase production in the near term, but the loss of forests can reduce productivity in the long term.

About **76** nations, containing about half the world's population (2 billion), are located entirely or largely within the tropical latitudes (fig. 9). These nations are characterized by fast-growing populations, low per capita incomes, and agrarian economies. Some of their agriculture is subsistence farming in upland areas where soils have low fertility or are dry. Some is commercial agriculture on the more fertile and generally irrigated alluvial plains of major river valleys. The success of both types of agriculture is linked to the status of *1.2* billion hectares (ha) of moist tropical forest and *800* million ha* of drier open woodlands.

● This report refers to land area in hectares (ha), One hectare equals 2.47 acres. One square kilometer equals 100 ha. One square mile equals 259 ha. Thus 1.2 billion ha of moist tropical forest is 3 billion acres or 4.6 million square miles.

Because the population structure in tropical countries is dominated by young people, food and other needs are growing faster than population (fig. **10).** For example, food production in developing nations needs to increase by about 4 percent per year, while population is growing at about 2 percent. The age structure also means that population growth has a built-in momentum that will prevent the numbers from stabilizing until well into the next century, if then **(80).**

Part of the needed gains in agricultural production can come from improved irrigation, crop breeding, and technical inputs that enhance agricultural yields. But average yields probably cannot increase every year by 4 percent. Two percent gains may be possible, but to sustain even that rate over several decades will be very difficult. Consequently, the amount of land farmed and grazed will have to be expanded and people will continue to clear forests to produce food and other goods.

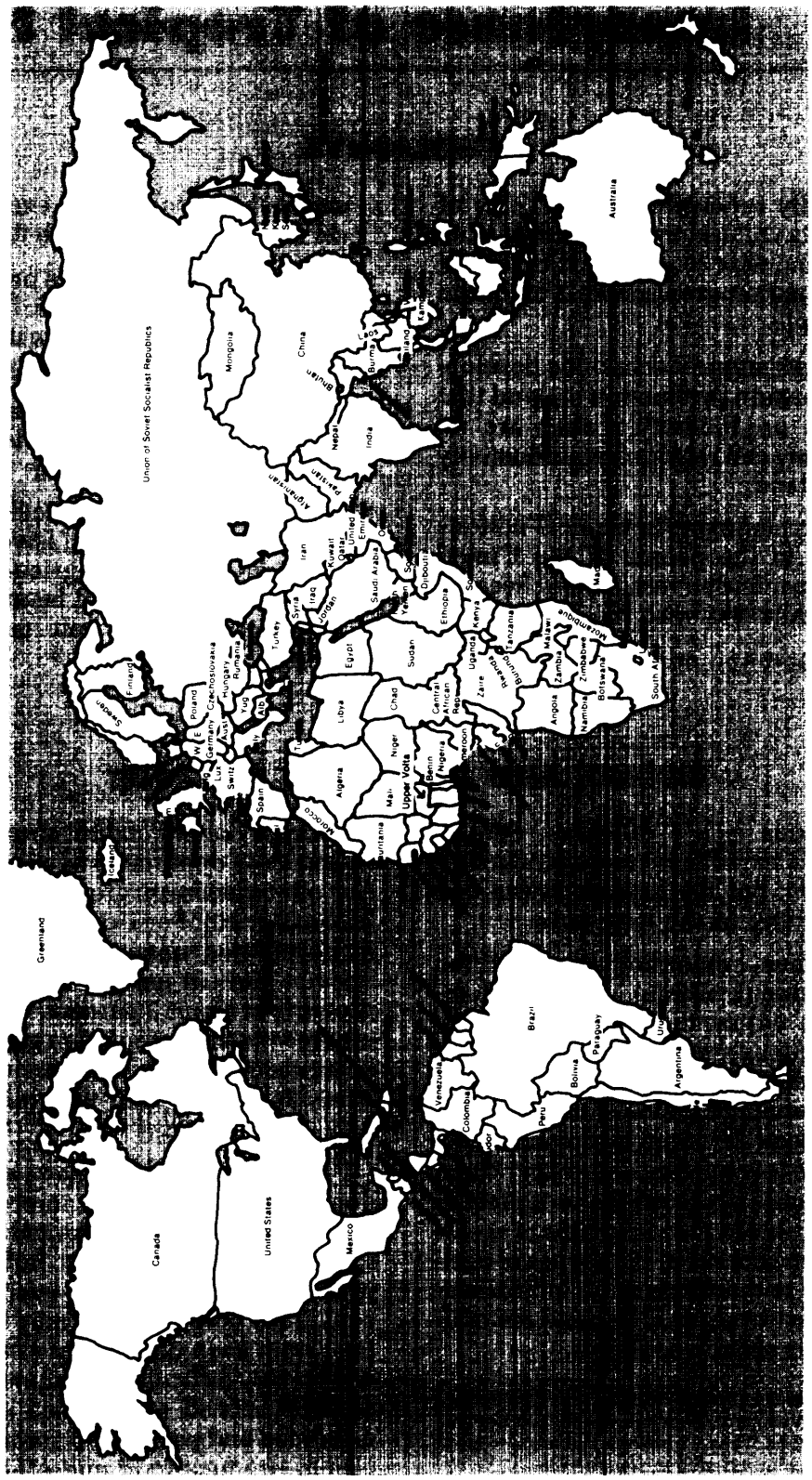


Figure 9.—Tropical Forests and Woodlands Are Located at Latitudes South of 23.5° N and North of 23.5° S, and at Other Frost-Free Localities

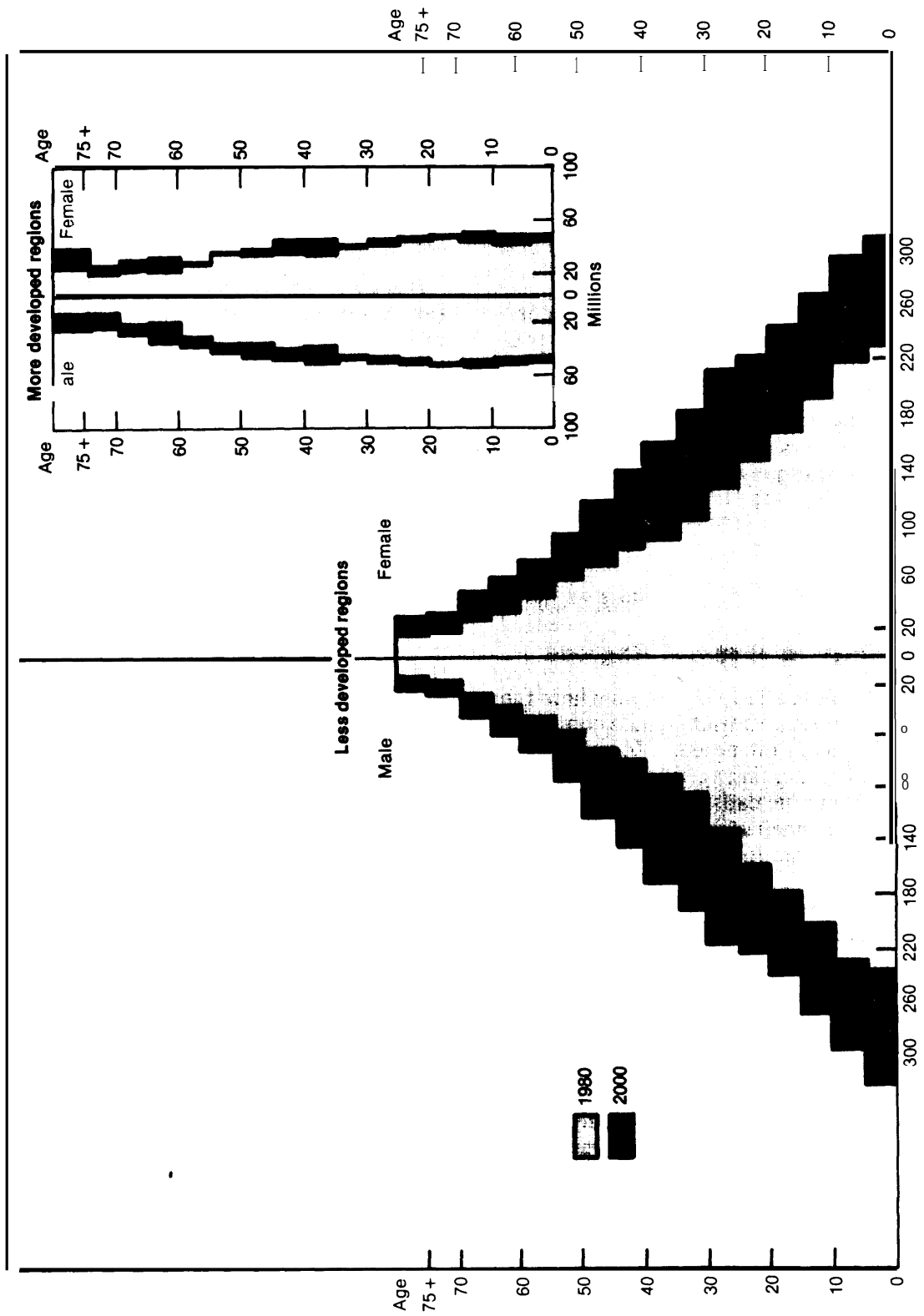


Figure 10.—Age-Sex Composition of More Developed and Less Developed Regions, 1980 and 2000

SOURCE: U.S. Bureau of the Census, Illustrative Projections of World Populations to the 21st Century, Special Study Series, table 2, pt. B, p. 23, no. 79, January 1979. *In:* U.S. Congress, Office of Technology Assessment, *World Population and Fertility Planning: The Next 20 Years*, OTA-HR-157, February 1982.

Population growth rates and the number of young people in tropical populations also result in a rapidly growing labor force. But in most tropical nations, it does not seem likely that industry and commercial agriculture will be able to sustain growth of over 2 percent per year in job opportunities. Thus, substantial numbers of people will turn to the forests—either clearing them for conventional farming and grazing, or managing them for forestry and agroforestry production.

The need for food and jobs is direct and compelling, while the environmental services provided by tropical forest resources affect tropical people indirectly and forest loss becomes apparent slowly. In the long term, tropical people need the watershed protection, preservation of habitat and genetic diversity provided by the forests (fig. 11).

One approach to accommodate the conflicting needs of tropical people is to accelerate economic development of resources outside the forest to provide food, goods, jobs, and foreign exchange. This would reduce the need to exploit and clear tropical forests. While this may have the greatest effect in the long run, these types of technologies (e.g., improving tropical agriculture) are outside the scope of this assessment.

A second approach is to direct the use of forest resources so that both sets of needs—provision of food, jobs, and national income and maintenance of the forests' environmental services—are fulfilled.

WATER AND CLIMATE

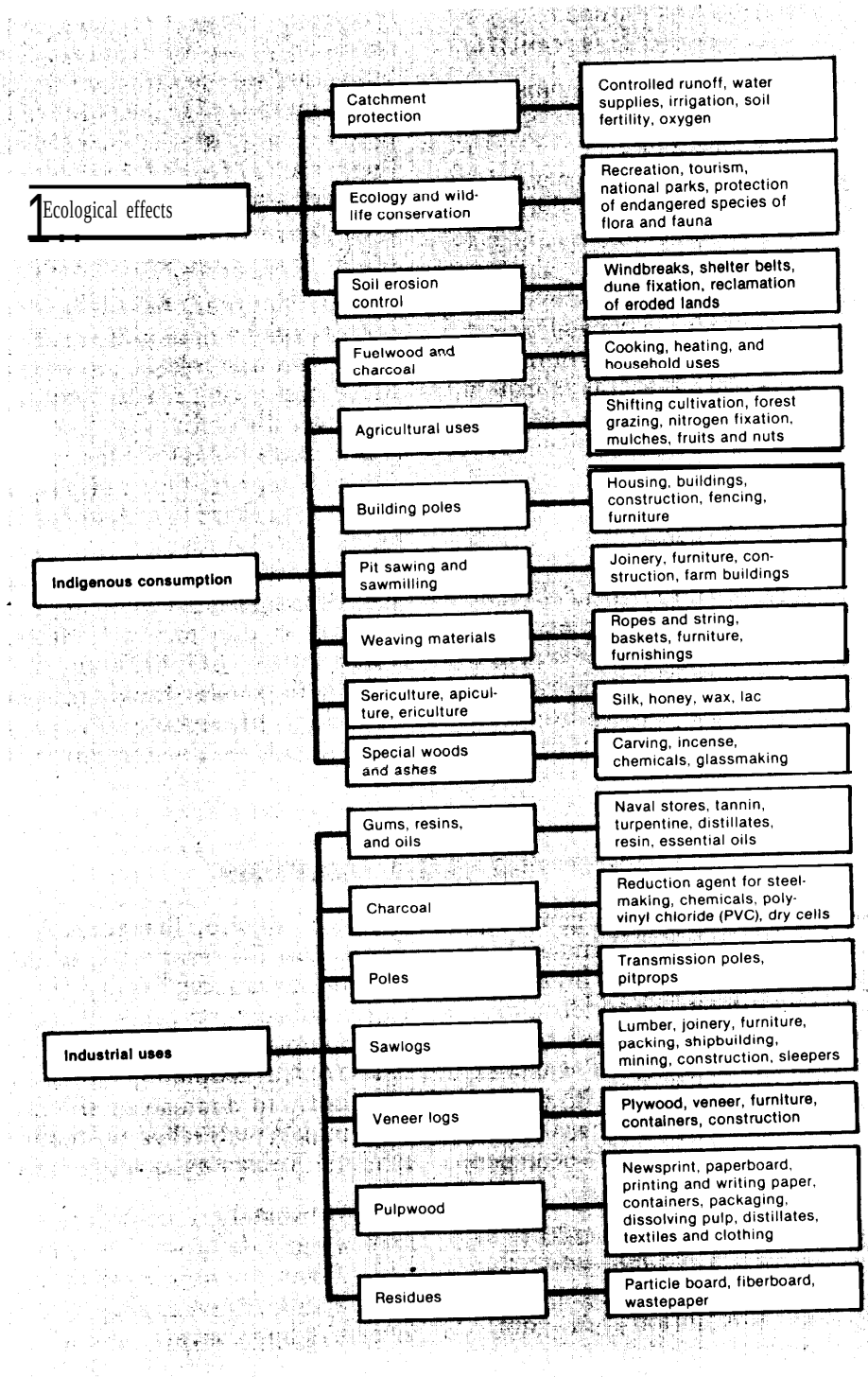
Hydrology in Tropical Regions

Most rainfall in the Tropics occurs where the northeast and southwest trade winds converge. This Inter-Tropical Convergence Zone is intrinsically unstable, oscillating to the north and south of the Equator, causing an erratic rainfall pattern with sharp seasonal contrasts (49). When tropical rains do fall, storms are more violent than those in temperate areas. More water falls per storm, quickly saturating the soil. Consequently, a larger proportion of the rainfall runs off the soil surface. Furthermore, in tropical storms raindrops are larger, thus having great kinetic energy and high erosive power (1,59). For example, in areas of the Amazon Basin where annual rainfall averages 2,100 millimeters per year and land slope is about 15 percent, erosion removes only about 360 kilograms of soil per hectare per year from forested land. But after the forest is cleared, erosion increases 100 times (43).

Tropical forests protect soil and modulate water flows in several ways. The canopy of leaves intercepts rainfall and provides temporary water storage. In addition, organic litter on the soil surface and the porous topsoil store water. The organic litter in closed tropical forests is typically 10 to 30 centimeters thick and the topsoil has a high organic material content (49,61). These mechanisms minimize the impacts of intense rainstorms, reduce peak stormflows, and help mitigate flooding.

The effects of forest cover on streamflow have been measured in tropical regions. In a moist montane forest in Kenya, for example, water measurements were taken on two adjacent 600 ha valleys for over 25 years. When one valley was cleared for a tea plantation—leaving the steeper slopes and riverbanks under forest—the immediate effect was a fourfold increase in peak stormflow. Even after installing conservation practices (e.g., contour planting, cutoff drains, cover crops), stormflows remained double that measured in the undisturbed forest, although the total flows were small (49). Similarly, an experiment was conducted in India on a forest which had been reduced to wasteland by fuelwood cutting and overgrazing. When the severely eroded Siwalik hills of

Figure II.—The Role of Forests



SOURCE: World Bank, Forestry Sector Policy Paper (Washington, D. C.: World Bank, 1978).

Chandigah were reforested, the peak rate of flow from the watershed was reduced 73 percent and total flow was reduced 28 percent (73).

In dry environments where tree canopies are open, forests are less effective in protecting the soil and modulating water flows, but their influence is still beneficial. Open forests provide shade and act as windbreaks. They reduce soil surface temperatures and wind erosion and stabilize streambanks. They can anchor shifting sand dunes that can otherwise destroy croplands and irrigation systems, In coastal plains, trees can prevent the rise of saline ground water. Trees in arid areas, however, may through evapotranspiration leave less water available for human uses (49).

Local Climate

Tropical forests also can affect local climate. In moist forests with closed canopies, transpiration of water extracted from the soil and the direct evaporation of intercepted rainfall cool the surrounding air. The resulting cooling effect is pronounced, increasing the occurrence and persistence of mists. Thus, the heat flux from a closed tropical forest in the dry season is only half that from similar land covered with subsistence crops or rough pasture (49). Crops cultivated in and near the forest are likely to enjoy greater soil moisture content than those on cleared land, provided that they are planted beyond the root-spread of the trees. Similarly, windbreaks and shade trees can improve microclimates for crops in dry areas.

Some mountain forests in low rainfall areas collect useful amounts of water by condensation from mists and release the water as "drip-fall," sometimes giving rise to perennial streams (49). However, the belief that forests actually cause rain is questionable. (One recent study in the Amazon reports that a significant part of the rain falling there is water evaporated from the forest, but the results have not been verified by other studies.) The dessication that is so frequently a consequence of large-scale forest destruction is due to the hydrological damage caused by loss of infiltration and underground storage. In general, forests thus have a critically important influence on the reception of rainfall, but not on its generation (49).

TROPICAL AGRICULTURE

The populations of tropical nations generally are concentrated on the coastal plains and in the valleys of the great rivers. Most forests in these areas already have been cleared for croplands. Much of this land is irrigated by old systems that control the drainage of seasonal floodwaters. Land that is irrigated with newer systems uses large dams to store excess floodwater and can produce more than one crop per year,

The most productive tropical agriculture is based on annual flooding, but it fails when the floods are severe. New high-yielding crop varieties of the Green Revolution are short-stemmed and so require precise control of water levels. Excessive flooding also can result in shortages of reservoir water for irrigation in the following dry season. Further, the accelerated siltation that accompanies abnormal floods can fill reservoirs, canals, and stream channels, reducing the precision of water control in subsequent years. Thus, the Green Revolution not only increased production from the best tropical croplands but also increased susceptibility to damage by floods and siltation. This makes watershed protection provided by tropical forests even more important.

Unfortunately, recent decades have been a time of rapid deforestation in many tropical nations. Consequently, river flows have become more erratic, flood damage to crops and structures has been severe, and siltation of waterways and reservoirs has increased (49).

The modulating effect of forests on streamflow and the consequences for agriculture are

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most evident when the protective forests have been destroyed. In Pakistan, for example, some 70 million people depend on 14 million ha of irrigated land in the Indus Basin for food. The irrigation depends on river flow, but deforestation on the Indus' headlands has resulted in increased peak flows during the monsoons, followed by water shortages during the dry season, With World Bank funding, two dams, the Mangla and the Tarbella, were constructed for hydropower, flood control, and irrigation. Careful studies of sedimentation rates had indicated that these dams would repay construction costs by providing benefits for many decades. However, parts of both watersheds have suffered uncontrolled deforestation and these reservoirs are filling with sediment at twice the expected rate (49]. Similarly, siltation is expected to reduce the lifetime of the Hirakud reservoir in India from 110 years to 35 years (57).

In India, the area of agricultural land damaged each year by floods continues to increase as deforestation occurs. The area of moist forest cleared each year is about 147,000 ha (29), and the area flooded has risen 18 percent over the past 10 years, from 22 million to 26 million ha (72). Clearing of forests over the past 20 years in India has caused flood and erosion damage estimated at U.S.$36 billion in 1982. This estimate includes loss of topsoil, loss of

nutrients, loss of property to floods, and shortened reservoir lifetimes (57).

Flood control and irrigation also are important in Central America. By the year 2000, Costa Rica and Panama plan to expand their irrigated areas by 180 percent and 340 percent, respectively (45). Yet, in these countries deforestation is rapid and uncontrolled. In many Central American locations, water needs for irrigation, consumption, industry, and navigation are reaching the limits of low-season flows. Half of the region's forests have been cleared in the past 25 years and water flows are becoming more erratic as deforestation continues (26,45, 77]. Similarly, in Africa along a broad belt bordering the equatorial humid tropical forest and along the Gulf of Guinea, the forests are being destroyed. Consequently, several nations in the region are expected to suffer agricultural water shortages before the end of the century (77).

In addition to watershed protection for the current year's crops, forests have longer term values for agriculture. Farmers throughout the world are using more high-yielding crop varieties. In fact, about half the increase in agricultural production in recent decades can be attributed to plant breeding (81). The reliance on high-yielding varieties has reduced the genetic diversity of agricultural systems and so increased the risk of catastrophic damage from diseases, pests, and other stresses. Yet, no great increase in crop failures has occurred. This is due to new methods of crop protection and the ability of crop breeders to respond to threats quickly by breeding new traits into the crops—traits sometimes obtained from wild relatives in the tropical forests. For example, a recent improvement in resistance of peanuts to leafspot was derived from breeding crop varieties with wild forms from the Amazon region. The estimated benefit from this one improvement is $500 million per year (47).

The peanut is just one of many crops with ancestors in tropical forest areas (58). Other cultivated tropical plants include plantains, yams, tare, cassava, sugarcane, potatoes, and cowpeas. Tree crops with tropical forest ancestors and relatives include oil palm, rubber, coffee, cocoa, and many important fruits. These tropical plants account for at least half the calories consumed by people in the Tropics (47), as well as many commodities important to the U.S. economy. Future gains in productivity from breeding these important agricultural crops may depend on the genes in their wild progenitors and, thus, on the continued existence of tropical forests and associated natural areas.

For the people of the Tropics, damage from increased flooding and siltation and the potential loss of crop breeding opportunities mean poorer nutrition, slower economic progress, and less prospect of achieving prosperous, stable economies. For the United States, this means the affected nations are less able to trade internationally. The developing nations already are a major market—and the fastest growing market—for U.S. exports. Their purchases from the United States in 1982 were valued at $82.7 billion, over one-third of all U.S. exports (82).

BASIC HUMAN NEEDS

Wood for Fuel

Wood is the most important source of fuel in most tropical nations (two exceptions are Brazil and Mexico, where oil and gas provide a greater share of total fuel than wood). One and one-half billion people in developing countries meet 90 percent of their energy needs with wood and charcoal. Another billion people meet at least 50 percent of their energy needs this way (25).

Fuelwood, however, is becoming harder and harder to find. Some 100 million people already are experiencing acute fuelwood scarcity and another billion are affected by lesser shortages

Photo credit: R?. C. Ghosh

Collecting firewood in the dry, open forests of Madhya Pradesh, India is arduous labor for women. Because the quantity collected is greater than the annual growth, finding enough wood takes more and more time each year

(30). In some countries, it can take up to 300 person-days of work to satisfy one household's annual fuelwood needs—forcing some dramatic changes in lifestyle. For example, many families in Upper Volta eat only one cooked meal each day, and in Senegal, quick cooking cereal (e.g., rice) has replaced more nutritious, but slower cooking, foods (e.g., millets) (64). Fewer families can avoid the "luxury" of boiling their water (76) and some are forced to keep children out of school to search for wood.

Fuelwood shortages are forcing increasing numbers of people to burn animal dung and agricultural wastes, with adverse impacts on land productivity. It has been estimated that if the cow dung burned for fuel in Asia, Africa, and the Near East were used for fertilizer, grain production could increase by 20 million tons a year (4).

Other Basic Human Needs

The exact number of people living in and near tropical forests, relying on the productivity of forests to supply their basic needs, is not known. The U.N. estimates that about 28 million people practice shifting cultivation in the closed tropical forests of Asia, 20 million in Africa, and 40 million in Latin America—totaling some 88 million people (31). This means some 3 to 4 percent of the total agricultural population in Asia, about 10 percent in Africa, and 35 percent in Latin America, work inside the closed forests. These estimates include ethnic populations practicing shifting cultivation as a traditional way of life. They do not include nonagricultural people who are purely hunters and gatherers, nor people who recently moved into forests. This can be significant, since in tropical Asia, at least, squatters probably outnumber shifting cultivators.

Many millions of additional people live in drier, mixed tree and grassland environments (open woodlands). These people are typically livestock herders and dryland farmers; yet, they too are directly dependent on the woodland environment. Their livestock feed on trees and

Photo credit: U.S. Agency for International Development

As fuelwood becomes more scarce, the burning of animal dung increases, depriving the land of nutrients

bushes, especially during dry seasons when grasses provide poor fodder. People living in open woodlands use wood for cooking, boiling water, heating, drying crops, and as fuel for small industries. Open woodland dwellers, like the people of the closed forests, use trees and wild plants for medicines, soaps, and many other basic needs (86).

Food from the forests—both closed and open—meets a significant part of the world's nutritional needs. Meat from wild animals, fruits, nuts, honey, insects, fungi, and foliage are all important forest food sources. At least 500 species of edible leaves are used in Africa alone (42). "Bush meat," including rodents and reptiles as well as wild ungulates and other mammals and birds, supply as much as 75 percent of the animal protein consumed in some tropical regions (20).

Forest trees and vegetation are the main materials used in the Tropics to build homes and buildings. In many rural societies, wood frequently is preferred even when other materials are available (91). Local wood also serves as poles, fences, stakes, furniture, tools, and utensils. Substitutes for these products are rarely available in subsistence cultures. Various fibers derived from forest vegetation are also important, especially for household use. Rattans, for example, are climbing palms used for cane furniture, baskets, mats, and similar uses.

In the northwestern Amazon forest alone, at least 1,300 plant species have been used by native people as medicines and drugs (62). Traditional healers in Southeast Asia use some 6,500 plants as treatments for malaria, stomach ulcers, syphilis, and other disorders, and also as sedatives and emetics (50). A number of these plants identified and tested by native people through generations of trial and error yield exceptionally promising compounds when screened in modern laboratories (21,24).

Forests also protect both inland and coastal waters, providing another important benefit to people. After deforestation, increased runoff accelerates erosion and carries excessive amounts of sediment to nearby lakes, reservoirs, and streams. For example, as early as *1904* erosion resulting from deforestation was responsible for clogging the once-navigable Rio das Velhas in Brazil to such an extent that even canoes ran aground (87). Today, deforestation is much more widespread in Brazil, and other navigable rivers such as the Cuiaba and Sa˜o Francisco have large parts filled with silt from eroded forest soils (3,8). Inland waterway transportation is further damaged by the seasonal drying up of local streams that can be a consequence of deforestation (18,88).

Increased erosion caused by deforestation has accelerated siltation of the Panama Canal's system of reservoirs at the same time that accelerated runoff has diminished water storage in the Canal's watershed. During a 1977 drought, the canal was closed to large vessels because of low water, a situation that experts believe may occur with increasing frequency unless watershed forest cover is restored (85).

Another impact of deforestation on tropical waterways relates to the release of nutrients from the forest biomass and soil. Organic matter production is sharply reduced under nonforest conditions. Further, the soluble nutrients from the ash of burned forests and from rapidly decomposing soil organic matter are easily leached from soil by heavy rainfall. The resulting increased nutrient content of runoff can accelerate the growth of noxious plants and algae in nearby lakes, canals, and rivers. Aquatic weeds block canals and pumps in irrigation projects. Also, they interfere with hydroelectric production, waste water through evapotranspiration, hinder boat traffic, increase waterborne disease, interfere with fishing and fish culture, and clog rivers and canals so that drainage is severely retarded and floods result.

In India, for example, plants reduce water flow in some large irrigation projects by as much as four-fifths. Rafts of water hyacinth weighing as much as 300 tons float over rice paddies in Bangladesh during floods. When the water recedes, the weeds settle and kill the germinating rice. Maintaining forested watersheds would reduce erosion and runoff, reduce populations of aquatic weeds, and reduce the cost of maintaining waterways.

Forests also act as a buffer against the force of typhoons and other violent storms in coastal zones. Tropical Asia, for example, suffers an average of 57 typhoons each year, causing storm damage that averages $2.8 billion (92). Forests reduce the destructive energy of these storms by deflecting wind and reducing the occurrence of landslides and other environmental damage.

Tropical storms are most violent in coastal areas, typically the areas that are most populated. Yet coastal forests are being eliminated more rapidly than most other types of tropical forests, with sometimes devastating effects (45). For example, Bangladesh has a coastal zone of 20,000 square kilometers that supports 20 million people. This nation's coastal areas were extensively cleared in the 1960's, leaving little protective forest. When a severe typhoon struck in 1970, 150,000 Bangladeshis drowned (35,65). Each year, typhoons and floods together claim the lives of 200,000 people and destroy many hundred thousand hectares of crops (92). A portion of these lives and crops could be saved if forest cover were maintained and enhanced (45).

About 15.5 million ha of mangrove forests grow along coastlines and in estuaries in tropical America, Asia, and Africa (31). These forests have several important functions aside from acting as a coastal buffer against storms, seawash, and floods. They also process sewage, absorb nutrients and heavy metals, and precipitate sediments, Most importantly, they provide ideal breeding and nursery grounds for various fish, molluscs, and crustaceans. Many valuable shrimp species breed at sea, after which the young move into mangroves where they seek food and protection. Mangroves also provide nurseries for such commercially important fishes as mullet, grunts, and milkfish (66).

Employment

Forest management and forest products industries can be a major source of employment in tropical countries. Industrial wood harvest in tropical forests takes about 60 person-days per hectare. Planting trees takes even more labor because site preparation usually involves more cutting and tree removal than does harvest (63). Table 2 is a summary of estimated annual person-day requirements for various forest plantation operations in World Bank projects.

Some tropical governments view tree planting as a way to reduce unemployment (33). For example, planting programs are planned with employment as a major benefit in various areas of Brazil. In the states of Minas Gerais and Espirito Sante, a large work force plants 100,000 ha/yr by hand, and in the Amazon region two large companies only do hand-planting. Similarly, large-scale, labor-intensive programs have been developed in Colombia, Venezuela, the Philippines, the Republic of Congo, and other Asian and African countries, and smaller programs are under way in Guatemala and Honduras (89).

Forestry and agroforestry require protection and management and so provide even more employment opportunities. Using agroforestry systems including cultivated crops, several tree crops, and livestock on a 100-ha farm in India, employment is estimated to rise from 20 to 50 people at the final, sustained yield stage. Thus, agroforestry systems to reclaim 5 million ha of India's degraded lands might employ 2 million people (57). Furthermore, forest products could serve as the basis for cottage industries, providing more employment and producing goods for domestic use and export.

Table 2.—Estimated Annual Person-day Requirements for Various Forestry Operations

Plantation design
Spacing: 600-2,000 trees per hectare (ha)
(more for energy plantations)

Task	Person-days
Nursery work/1,000 plants	7-13
Land clearing and burning/ha[a]	10-50
Pitting for planting/ha	3-15
Weeding/ha/yr [a]	6-36
Pruning/ha .,	5-15
Thinning, ,	8-11

[a]These measures vary greatly according to site conditions.

SOURCE: P.J. Wood, J. Burley, and A. Grainger, "Technologies and Technology Systems for Reforestation of Degraded Tropical Lands, " OTA commissioned paper, 1982,

Mangroves

Mangrove forests are important-economically and ecologically. However, mangrove ecosystems can be damaged by human activity. Deforestation of watershed areas can accelerate deposition of sand, silt, and clay in alluvial areas; changes in the pattern and volume of freshwater runoff can be attributed to irrigation, roadbuilding, and other such projects; coastal engineering practices may bring about a change in tidal flushing regimes. Other major stresses include pollutants such as pesticides and insecticides used in large agricultural projects and recurring oil spills due to the exploitation and transportation of offshore oil.

Several mangrove species are highly valued as firewood because they burn evenly with little smoke, and as charcoal because they have high caloric value. Charcoal for commercial sale is the main mangrove product in several Asian countries. Mangrove poles are used extensively for rural houses, foundations, and scaffolding of urban construction because the wood of many mangrove species is durable and resistant to termites (14). In recent years, mangrove has been harvested for woodchips to be used in chipboard manufacture, newspaper, and as a source of cellulose for rayon (71). The conversion of mangrove land to aquacuhure ponds also is increasing, which could have potential to increase fish production. However, improper site selection and poor design could have substantial negative impacts.

Management of mangrove forests can be complicated. In clearcut mangrove areas, increased temperatures and evaporation can raise soil salinity so that mangroves are unable to regrow. Hand planting of seedlings is possible but costly. Selective felling systems that retain trees below certain diameters often involve rather complicated regulations that may be difficult to administer. Natural regeneration can be enhanced by clearcutting narrow strips so that nearby trees can provide seeds.

The pressure to clear additional mangrove forest areas for agricultural, industrial, and aquacultural purposes will continue and the demand for fuelwood and poles will increase. Short- and long-term socioeconomic impacts of all alternative uses of mangrove forest areas must be evaluated to determine the optimum uses. It is only partly known, for instance, to what extent marine species are affected by removal of mangrove forests. Improved understanding of this important interaction could have significant forest management payoffs.

COMMERCIAL FOREST PRODUCTS

Wood

The principal commercial products of tropical forests are timber and fuelwood. Tropical hardwoods are used to produce lumber for construction, poles, pilings, railway ties, props in mines, and panel products such as plywood, veneer, fiberboard, and particle board. Hardwood is also important for finished goods such as furniture and paper products. In addition, some softwoods from tropical forests are used for lumber and pulp.

Most tropical forest wood is used within the country of origin and the economic value of this domestic consumption is difficult to assess. Value estimates exist for the 6 percent of the commercial tropical wood harvest that is exported. The total value of wood and wood product exports from the tropical nations has increased by about 500 percent in the past 10 years (32). Indonesia's wood exports in 1980 earned some $1.9 billion, The value of wood exports for Malaysia was $2 billion in 1980; for the Philippines, $415 million; for Brazil, $8I6 million; for the Ivory Coast, $415 million [32].

World trade in tropical wood is significant to the economies of both the producing and consuming nations. The largest single importer is Japan. Several other large importers—e. g., Singapore, Hong Kong, and South Korea—

reexport most of the wood to industrialized nations after partial or complete processing.

The United States is the second largest importer of tropical wood products and little of this wood is reexported. U.S. hardwood imports in 1978 amounted to $682 million, with tropical countries (principally Southeast Asia) supplying 82 percent of the total. Imports of tropical wood (logs, lumber, plywood, and veneer) averaged $430 million annually from 1974 to 1978, Although the dollar value of these imports seems high, on a volume basis they account for only 1 to 2 percent of all wood used in this country (85). U.S. demand for tropical wood has been growing at rates well above our population and the gross national product growth rates.

Both in the Tropics and in the importing nations, industrial hardwood is used mostly in the housing industry, so industrial demand for tropical wood has grown at a rate that generally follows housing starts. The paper industry is the other major wood user, but it primarily uses softwoods, for which the United States and Canada are major producers. Many tropical nations import paper, and the papermills located in the Tropics still import most of their softwood pulp from the temperate zone. Some tropical nations have begun to use their own natural pine forests, pine plantations, and, in a few cases, hardwoods as a source of pulp. But tropical forests still produce no more than 10 percent of the world's paper and paperboard.

This is likely to change in the next few decades. New technologies, some developed by the U.S. Forest Products Laboratory and U.S. forest industry, make it possible to produce high-quality paper pulp from 100 percent hard-

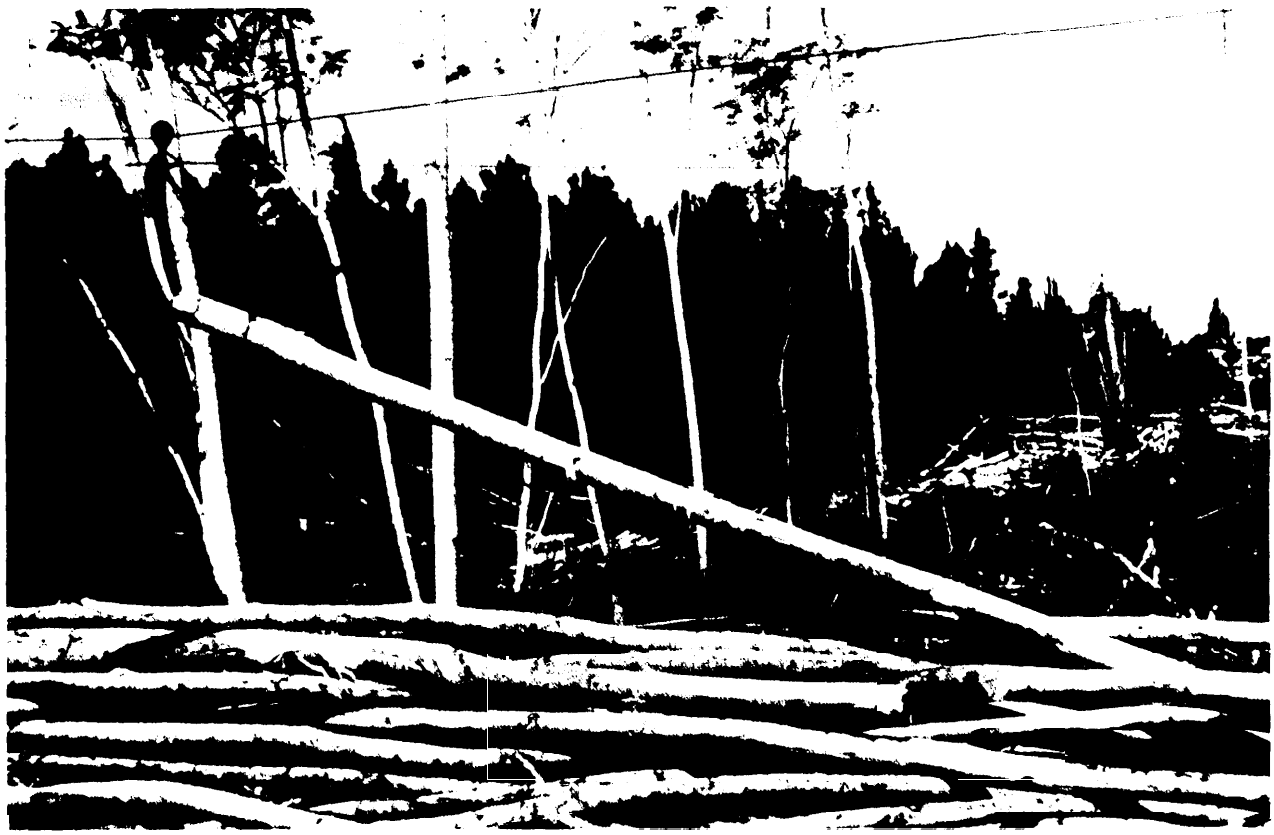

Photo credit: H. Bollinger

Wood, a major export item for Malaysia, is no longer restricted to sawlogs. Here 8-year-old *Albizia falcataria* trees (a legume species) are harvested for export to the Japanese pulp and paper market

woods and from a mixture of many hardwood species (84). International demand for tropical hardwood chips is expected to rise substantially as the new technologies are installed in papermills in wood-scarce Japan and in Europe, where wood shortages are anticipated. Japan already uses hardwood chips for over half of its pulpwood needs (46).

Demand for hardwoods for paper production also will increase within those tropical nations that have growing economies. As income increases, demand for paper products rises rapidly among relatively poor consumers as long as wood supplies are abundant (17).

Fuelwood and charcoal enter commerce for both household use and industry. Wood fuels have become much more important for industries in tropical nations since the rapid rise in fossil fuel costs. Wood is the least expensive energy source available for many cottage industries and charcoal the highest quality local source for some uses. For example, Brazil has 1.5 million ha of eucalyptus plantations established to supply charcoal to the iron and steel industry in the state of Minas Gerais (31).

The Philippine Government is planning two large wood-consuming industrial facilities in the province of Ilocos Norte. The first of a number of 3-megawatt "dendrothermal" electric powerplants dependent on wood from fast-growing trees as boiler fuel is under construction. Another project that will involve two large pig-iron blast furnaces and will rely on charcoal from local wood is being planned (36).

Products for Medicine

The importance of the tropical forests, especially the moist forests, as a source for medicines is largely a result of their high biological diversity. Some of these forests contain communities of species that have existed for 60 million years, making them the oldest continuously established land ecosystems known. Their great age and ecological stability have allowed evolution to proceed in a relatively undisturbed manner, and it is probably due to this stable history that tropical moist forests developed their extreme biological richness (45).

Because tropical moist forests contain so many species, each species must compete with and defend itself against many potential enemies, and one way to do this is by developing alliances (e.g., symbiosis) with other species. Thus, tropical forest species are highly interactive. The millions of plant and animal species also have had time to develop complex chemicals that help them interact with other species. It is because of these "biologically active" chemicals that the tropical forests are considered Earth's richest storehouses of potential drugs.

Today, medical science is highly dependent on chemicals produced naturally by plants. One-fourth of all U.S. prescriptions contain ingredients from higher plants (27). In 1974, the United States imported $24.4 million worth of medicinal plants to produce about $3 billion worth of drugs. The commercial value of these products is over $8 billion per year. When nonprescription items are included, the value doubles (28).

Although chemical screening has been done on less than 1 percent of the tropical species, already some 260 South American plants have been identified as having potential for fertility control. Some 1,400 tropical forest species are believed to have anticancer properties (7,16, 21,68,70). The National Cancer Institute has screened about 35,000 higher plant species for activity against cancer. As of 1977, about 3,000 of these had demonstrated reproducible activity and a smaller number were appropriate for clinical trials (23). Rotenoids from the roots of tropical trees, for example, are being tested clinically in the United States as antitumor drugs.

One tropical plant, the rosy periwinkle, has had a profound effect on treatment of leukemia. In 1960, people suffering this disease faced one chance in five of remission. But because of two drugs developed from the rosy periwinkle, the chances of remission are now four in five (41). ***Tabebuia serratifolia, Jacaranda caucana,*** and ***Croton tiglium*** are tropical trees, and each produces a unique anti-cancer compound whose effectiveness has been proved in the laboratory (51).

Tropical forest plants are significant in treating other medical problems, notably hypertension (2,41,44,67). D-tubocurasine, made from the South American vine ***Chondrodendron tornentosum,*** is widely used as a muscle relaxant in surgery in the United States, Chemists have been unable to produce it synthetically in a form having all of the characteristics of the natural product (52). The drug's supply, therefore, continues to rely on extracts from wild plants.

Tropical forest animals are also necessary to medical science. Primates are the most important group. They are used widely in medical research and pharmaceutical trials.[1] Tropical primates are especially important because of their similarity to humans. For example, research into malaria, cardiovascular diseases, cancers, hepatitis, and other diseases commonly uses rhesus monkeys, longtail macaques, squirrel monkeys, chimpanzees, African green monkeys, and owl monkeys.

Some 34,000 primates were imported into the United States in 1977 for drug safety tests and drug production (5). Virus-free polio vaccine perhaps is the most important of the drugs produced this way, using many thousands of tropicaI forest African green monkeys, The Central and South American owl monkey is the only known nonhuman animal suitable for malaria chemotherapy and immunology studies (5). Few of these important animals are raised in captivity; most are captured, and they are becoming scarce as their forest habitat is being destroyed.

[1]See ongoing OTA assessment "Alternatives to Animal Use in Testing and Experimentation. "

Other Forest Products

Tropical forests provide abroad array of nonwood products.z Some are produced in plantations of selected tree species. Others are gathered in natural forests and brought to market through a diffuse system of collectors and middlemen. These are often called "minor forest products, " although their importance frequently is greater than that term implies. For example, tropical forests provide essential oils, exudates, gums, latexes, resins, tannins, sterols, waxes, esters, acids, phenols, alcohols, edible oils, rattans, bamboos, flavorings, sweeteners, spices, balsams, pesticides, and dyestuffs.

Few nations have collected data on the commercial value of these nonwood forest products. One exception is India, where nonwood forest products are worth about $135 million per year, equivalent to one-fifth of the value of industrial timber (48,69). Indian forests also produce a substantial quantity of animals used for food, scientific research, and other purposes. In Indonesia, rattans generate an export trade worth up to $5 million per year. The world trade in rattan end products now totals $1.5 billion (22,37).

World trade in essential oils and spices from tropical forest plants, such as camphor, cassia, cardamon, citronella, and cinnamon, exceeds $1 billion per year. The United States now imports about 10,000 tons per year of these kinds of oils and spices, with a value of over $100 million (24,54,55). A systematic investigation of the many nonwood forest products used by the forest-dwelling people of the Tropics might lead to increased use of these materials and further enhance the economic importance of the forests.

[1]*See Workshop Proceedings on Plants: The Potentials for Extracting Protein, Medicines, and Other Useful Chemicals* (Washington, D. C,: U.S. Congress, Office of Technology Assessment, OTA-BP-F-23, September 1983), for additional information.

ENVIRONMENT

Endangered Species

Tropical habitats contain a significant number of the world's endangered species. As discussed earlier, tropical moist forests are both the most biologically complex and species-diverse* biome on Earth. The complexity is both dynamic (highly interactive) and stable (able to maintain itself for long periods). Yet the stability depends on an important provision—that external forces do not exceed certain critical thresholds. Human intervention may easily exceed these thresholds.

Because of geographic confinements and specialized ecological requirements, tropical moist forest species are unusually susceptible to extinction (46). Many species are found in only one small area, so even a limited amount of deforestation can exterminate entire species. Further, species are highly interdependent. For example, Brazil nuts are probably the most commercially significant food gathered from forests. The nuts will grow only where a particular type of bee lives, as only this bee can pollinate Brazil nut flowers. The bee, in turn, lives only where a particular type of orchid is found, because it must obtain a chemical from the orchid to attract its mate. Thus, the tree has not been domesticated away from the forest where the bees and the orchids are found. Further, for some of the nuts to serve as seeds, the nuts must be chewed by a rodent to soften the fruit, allowing seed germination. Thus, Brazil nut tree reserves must be large enough to support a breeding population of this rodent. Such complex systems of interdependence are another reason why entire species can be threatened by small changes (75).

At least three-quarters of the projected extinctions worldwide until the end of the century are expected to occur in tropical moist forests. Degradation and destruction of tropical forests and woodlands could precipitate a fundamental shift in the course of evolution (45). Of more certain concern is the loss of potential resources, not only chemicals and animals that may be used directly in medicine, agriculture, and other industries but also genetic information with great potential for biotechnology development.

"Biological diversity includes two related concepts, genetic diversity and ecological diversity. Genetic diversity is the amount of genetic variability among individuals in a single species, whether the species exists as a single interbreeding group or as a number of populations, strains, breeds, races, or subspecies. Ecological diversity (species richness) is the number of species in a community of organisms. Both kinds of diversity are fundamental to the functioning of ecological systems (17).

Migratory Animals

Tropical forests provide habitats for many of the world's migratory and endangered species. About two-thirds of the birds that breed in North America migrate to Latin America or the Caribbean for winter (74). In general, forest habitats are more important for migratory species than was previously thought. Many migratory species winter in tropical highlands—areas that have been rapidly preempted for agriculture. Since migratory species concentrate often in smaller areas in winter, the effects of clearing 1 ha of forest in Mexico probably are equivalent to clearing 5 ha in the Northeastern United States (74).

Migratory species have economic, environmental, and esthetic values in the United States. For instance, some migratory birds play an important role in integrated pest management systems for agriculture in the Eastern United States, yet they could become more scarce as their wintering grounds in the Tropics are lost to deforestation.

Climate

The question of whether tropical deforestation can disrupt the stability of world climates is highly controversial. The scientific understanding of the climate effects of deforestation is still theoretical. When forests are removed, more solar heat is reflected back into space (the "albedo" effect). Some scientists believe that this can lead to changes in global patterns of air circulation, with potential impacts on agriculture (53,60).

Another effect of forests on global climate is their role as a carbon reservoir in the carbon cycle. As large areas of forest are converted to nonforest, the carbon that had been stored in wood and in organic material in the topsoil is released to the atmosphere as carbon dioxide. When croplands, grasslands, or degraded brush replace moist forest, the new vegetation stores much less carbon, Thus, net annual deforestation adds carbon dioxide to the atmosphere (90).

The concentration of carbon dioxide in the atmosphere has been increasing for several decades, apparently more from burning fossil fuels than from deforestation, Scientists agree that continued increases in atmospheric carbon dioxide will produce a "greenhouse effect" leading to a global warming trend. Doubling of the atmospheric carbon dioxide would probably raise the average global climate by several degrees centigrade. Some scientists hypothesize that increased cloud cover and other environmental change will confound the greenhouse effect. The effects of such trends on agriculture or on the world's hydrological systems are unknown. Likewise, the role of the world's forests and the effect of substantial deforestation are still uncertain. Some scientists consider deforestation to be a significant factor in the concentration of atmospheric carbon dioxide, while others do not (10,12,15,19, 34,90).

POLITICAL IMPLICATIONS

Stability of the renewable natural resource base in tropical countries affects both the economic viability of U.S. investments overseas and the political stability of the host nations. Foreign assistance projects funded by the U.S. Government and development projects funded by the U.S. private sector are being undercut by flooding, siltation of reservoirs, pest outbreaks, and other problems associated with deforestation. For example, the reservoirs used to operate the Panama Canal are rapidly filling with silt (85), as are hydroelectric reservoirs in Pakistan, Thailand, the Philippines, Indonesia, and many other nations (49).

Food and jobs are critical for political stability in developing nations and both are reduced by inappropriate deforestation. Food supplies and employment can be increased in the long run, however, by reforestation of degraded land and by forest management. Frontiers of human settlement, with relatively untapped supplies of natural resources, historically are a source of new employment opportunities. Today, however, the remaining frontiers are mostly infertile or dry lands unable to support large numbers of people using current technologies. Thus, many rural unemployed persons migrate to the cities. As unemployment climbs, changes in the distribution of income within societies further aggravate social inequities and political stresses (11).

One consequence of the inability of developing country governments to create sufficient jobs is that people emigrate to countries with slower population growth and greater per capita resources. The flow of refugees from Haiti to Florida is sometimes cited as an example of the economic and social disruption caused, in part, by tropical deforestation and consequent environmental deterioration (9).

IMPORTANCE TO FUTURE GENERATIONS

Tropical forests have particular importance to future generations. With few exceptions present agriculture systems cannot accomplish sustained productivity on infertile or dry sites without expensive inputs of irrigation water or fertilizers. But scientific study of natural ecosystems, in concert with applied research to develop technologies, possibly can discover

how sustainable agriculture can be achieved on this land. Such research has hardly begun and it is a slow process. Thus, the tropical forests serve future generations by the information they reveal to science and by maintaining the quality of the land until sustainable systems for more intensive use are developed.

The Tropics are thought to be the repository of two-thirds of the world's approximately 4.5 million plant and animal species, only about 500,000 of which have been named. That means that about 2.5 million of the tropical species are yet unknown to science (58). * These unknown species are resources of incalculable importance for the future. Undoubtedly, new sources of food, drugs, fuel, and products lie undiscovered in tropical forests.

Although vertebrates are generally thought to be well known on a worldwide basis, only about 60 percent of the estimated 5,000 species of fish in the fresh waters of South America have been scientifically described and named, even though these comprise a large proportion of the diet of local people. A principal source of meat for Paraguayan farmers is a peccary, made known scientifically only in 1977 (58).

Tropical forests offer potential resources for plant breeding, genetic engineering, and other biotechnologies. Because farming environments are constantly changing as pests or plant diseases threaten or as weather changes, agriculture relies on the continued input of genetic diversity for plant improvement. Germplasm is the resource to which plant breeders turn for desirable characteristics—resistance to pests or stress, or improved growth qualities. A Peruvian species, for example, contributed "ripe rot" resistance to American pepper plants and a wild melon in India was the source of resistance to powdery mildew that threatened destruction of California's melon crop (47). A wild relative of the potato from Peru has been known for decades to be highly resistant to insects because of sticky hairs on its leaves, but this resistance has not been useful to agriculture because the wild plant cannot be crossed with domesticated kinds of potatoes. Now the sticky-hair characteristic is expected to be transferred with new biotechnology methods. If it works, the result could be new potato strains that have a much reduced need for pesticide applications. This implies substantial gains in production of this important food and attendant environmental benefits from reduced insecticide use, It is not possible to predict with accuracy what germ plasm will be needed in the future.

With the gradual consumption of fossil fuels and other nonrenewable resources, the United States and other nations are expected to turn increasingly to biological systems for industrial and chemical feedstocks and for solutions to pollution and other environmental problems (78,79). Some complex chemicals and some more simple biological processes can be invented in the laboratory, but most have to be found in nature.

Genetic materials and basic systems found in nature can be reproduced or adapted with bioengineering techniques. New techniques for cloning plants and micro-organisms already are enabling laboratory biologists to screen existing organisms for their production of useful chemicals much more rapidly and efficiently than in the past. The newly developing techniques for genetic manipulation offer opportunities to adapt existing organisms to new uses (79).

For example, tropical forests have a greater proportion of alkaloid-bearing plants than any other biome (6,39,56). Many of the plant species contain hydrocarbons as well as carbohydrates in their tissues. These plant tissues can be renewable sources for many chemicals, including fuels, now derived from nonrenewable fossil sources (13,38). Since tropical forest species usually are restricted to small geographic areas, opportunities are lost wherever the forests are removed before their unique biota has been identified, screened, and assessed for usefulness (83).

*No one knows how many species exist. Some estimates put the figure as low as 2 million; many converge on a figure of 5 million to 10 million; if tropical insect species are included, the number could be closer to 30 million (40).

U.S. Stake in Tropical Forests

Political Interests

- The United States has strong commitments to world peace, economic and social stability, and maintenance of the Earth's basic life-support systems, commitments that require concern about the integrity and long-term productivity of the global natural resource base, including the tropical forest component.
- The United States is party to a broad array of international resolutions, strategies, and agreements that call on all participating nations to promote and undertake improved management of the forest resource.
- U.S. public institutions and private firms conduct activities that directly and indirectly affect the forests of other nations and, therefore, are in positions to influence the attitudes and actions of host governments and local citizens toward the United States by their attention or inattention to sound resource management.

Economic Interests

- The non-oil-exporting developing countries purchase one-third of all U.S. exports. Adverse domestic natural resource conditions could seriously affect the ability of these countries to buy U.S. goods and services.
- U.S. economic growth requires a sustained supply of wood and wood products at a reasonable price. The United States will continue to look to imports from tropical countries to help meet the demand for certain hardwood products.
- Sizable U.S. investment in international development assistance programs can be undercut by deforestation-induced problems (i.e., intensified flooding and siltation).
- The world's closed tropical forests contain numerous little-known or undiscovered plant species, many of which are likely to have important uses as food crops, medicines, resins, and other industrial products. Many others are already used for such purposes.

Humanitarian Interests

- The United States is committed to meeting basic needs and supporting economic and social development in the less developed nations of the world which, in turn, is linked inextricably to the quality and integrity of the world's natural resource base. With increasing frequency, development programs are being affected adversely by deforestation-related problems.
- The United States and other nations have raised humanitarian concerns about indigenous populations whose cultures and very existence may be threatened by destruction of the forests.
- The United States increasingly is being requested by governments and internal tional development organizations to provide technical assistance and financial support for forest-related activities in developing countries.

Environmental Interests

- U.S. public institutions have statutory and policy responsibilities to protect and manage wisely the environment and natural resources of our Nation, as well as those of other areas within and outside U.S. jurisdiction in which U, S.-sponsored or U. S.-assisted activities are carried out.
- The United States shares, with South and Central America and the Caribbean area, hundreds of species of migratory animals, including birds, insects, marine turtles, and mammals, whose survival depends to varying degrees on tropical forests.
- The United States is committed to helping preserve the world's flora, fauna, and vulnerable ecosystems by virtue of domestic legislation and national policies, and by being party to a large number of international conventions and agreements. Principal among these measures are the Endangered Species Act of 1973, the Convention on International Trade in Endangered Species of Wild Flora and Fauna, and the Convention on Nature Protection and Wildlife Preservation in the Western Hemisphere.
- Large-scale destruction of the Earth's rain forests runs a risk of triggering global climate change, with uncertain but potentially adverse consequences for world food production and human well-being,

Educational and Scientific Interests

- The influence of tropical forest ecosystems on global physical, biological, and geochemical processes is poorly understood and requires long-term study.
- The unique flora and fauna of the tropical forests continue to provide outstanding scientific and educational opportunities.

SOURCE: U.S. Interagency Task Force, *The World's Tropical Forests: A Policy, Strategy, and Program for the United States*, Department of State Publication 9117, 1980.

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