Chapter 2
The Environment for Forest Production

The environment for making tropical forests productive depends on forest values, appropriate land, and production goals. This chapter deals principally with the physical environment for forest production and its development for that purpose. The recent rise in social concern for forests brings to the forefront a distinct feature of the environment that will be dealt with mostly in chapter 10. It is necessary here, however, to recognize that making tropical forests productive for human wants on the scale needed in the future calls for forest modification and plantations. It is imperative that such practices are acceptable socially. This requires that they meet the standards of silviculture in perpetuating the productivity of the basic resource, the soil, and that the public understands what is being done and why and accepts all the probable consequences. Without such understanding and acceptance, forest production will not be effective or even applied on a scale adequate to meet future needs.

Forest Values

The initial evolution of *Homo sapiens* is believed to have taken place on the margin of a tropical or subtropical forest (Leakey 1964, cited by Longman and Jenik 1974). Tribes later turned to forests to gather food and to take refuge during intertribal conflicts. For eons, forests have been slowing water movement and thus precipitating sediments, capturing nutrients, and building the soil upon which tropical peoples depend for subsistence. Forest-created agricultural potential dictates the level to which a human culture can develop (Meggers 1954). The presence or absence of forest cover may decide the ultimate fate of a human society (Sartorius and Henle 1968). Tropical America without forests probably could not have supported human life.

The largest forest area in tropical America, the Amazonian lowlands, has been inhabited only a few millennia (Sioli 1973). Human inhabitants evidently came as hunters and fishermen, collected wild food plants in the uplands, and adopted agriculture to some degree (Sternberg 1968). Since numbers were few, the tribes could satisfy their needs without seriously affecting the forest ecosystems. Exploitation was concentrated along the water and in *varzea* (seasonally flooded) forests. The rivers were so large that their waters completely digested human waste, and in many areas river water, at least until recently, still could be drunk without danger of intestinal infection (Sioli 1973).

The population of tropical America is not only as large as it probably has ever been—399 million in 1990 (Anon. 1993b)—but its growth has been very rapid, increasing at an average annual rate of 2.7 percent (Anon. 1976k). The mean population density, 18 persons per square kilometer, is similar to that of tropical Africa (16 persons per square kilometer), but much less than that of the tropical Asia-Pacific area (82 persons per square kilometer) (Anon. 1993b).

Forests and the Human Environment. In earlier times, the tropical forest provided a favorable environment for human habitation. Those areas closest to water and natural food sources were generally forested. Then, as population increased and tribal competition for these resources appeared, the forest provided refuge and security. It is still so used by the remaining indigenous peoples in tropical America. Tropical forests provide (in addition to wood) thatch, basketing, cordage, ornaments, canoes, starch, oils, plant and animal foods, glues, pigments, rubber, condiments, medicines, and poisons (figs. 2–1, 2–2; Levi-Strauss 1952).

Humans have only begun to discover the forest's importance as creator and conserver of an environment vital to

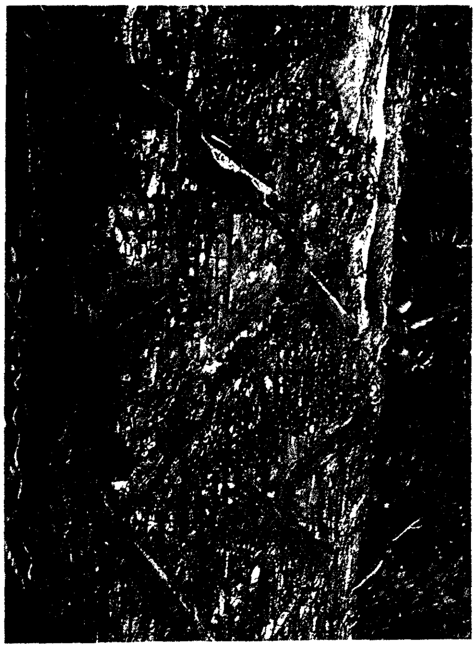

Figure 2–1.—*The trunks of virtually all chicozapote trees* (Manilkara zapota) *in Mexico and Central America have been tapped repeatedly for their latex as a base for chewing gum.*

Figure 2–2.—*Mangroves provide a locally accessible, highly productive source of straight poles for construction.*

human survival (Poore 1976b). The forest is a reservoir of genetic capital. Within it lie hidden secrets about natural materials, the ultimate utility of which is unknown, as well as opportunities for their preservation, production, and utilization. Knowledge of the many species harbored in forests, as well as their occurrence, behavior, and potential benefits, is essential for the full use of these resources. But, in many areas, such knowledge has declined with the transition from primitive forest peoples to modern societies. Many of the forests have been destroyed before their potential utility was even fully recognized.

The forests absorb and productively utilize solar radiation. They ameliorate microclimate by reducing extremes of temperature and available moisture. Significant effects on macroclimate (carbon balance with the atmosphere) have been postulated (Woodwell 1970) but have not yet been verified (Newell 1971). Forests absorb particulates and noxious substances from the atmosphere (Cliff 1973). They reduce noise levels. They may harbor organisms capable of causing epidemic diseases and pests deleterious to human society, but they also harbor other organisms that in nature provide means for preventing or controlling such outbreaks. Forests also go almost unheralded as effective, if limited, repositories for human wastes (van der Ploeg and Vlijm 1978). Near centers of high-density urban congestion, natural forest systems, such as mangroves, have been deliberately used to digest and recycle wastes. In summary, the forests of the Tropics serve as a giant and resilient buffer that minimizes environmental extremes and, within limits, compensates for aberrations caused by human intervention (fig. 2–3).

People are just beginning to understand the web of life in forest ecosystems—the interrelationships among species. This new knowledge will prove vital to the preservation of many species and to their sustained propagation under human management (Budowski 1976).

Animal life plays an essential, if subtle, role in maintaining the well-being of the forest. Many tree species would disappear were it not for the pollination and seed dispersal functions of animals. Also, the decomposition of forest litter is partly the work of microfauna. The additional roles of animals in preserving a balance among the less conspicuous components of the forest are probably vital to the welfare and restorative powers of forest ecosystems.

Forest animals provide social benefits as well. To hunters, primitive or modern, the fauna are an important source of food or sport. Throughout tropical America, most mammals and birds are forest dwellers. In the Amazon Basin, some farmers are said to rotate their cultivated fields on a 20-year cycle (although the soils are actually rejuvenated in 12) to allow more advanced successional vegetation for the benefit of game (Posey 1982). Along major rivers, edible aquatic animals may largely depend not only on the stability of the banks provided by tree roots but also on the food provided by forest litter falling into the water. Animal life in tropical

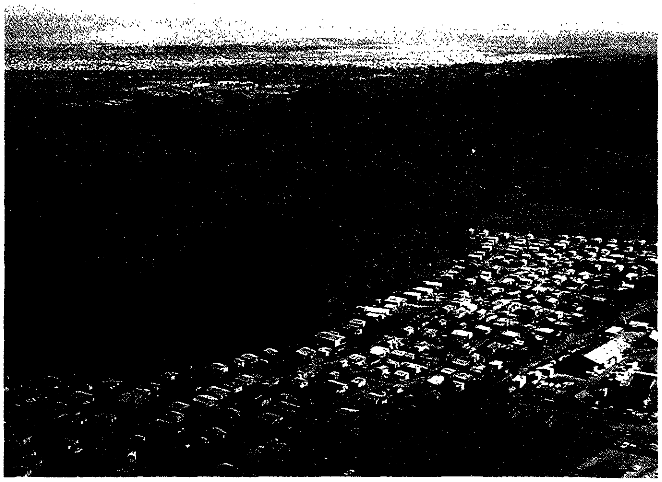

Figure 2–3.—*Despite urban sprawl, forests remain a valuable companion in northern Puerto Rico.*

forests is esthetically far more attractive than its current use for human enjoyment would suggest. Even so, it is becoming the primary source of public concern for the conservation of tropical forests.

Tropical forest ecosystems are highly efficient in the use and conservation of energy and other resources and have developed intricate mechanisms for preventing and repairing damage. They are a challenging and promising field for scientific study. Studies of forest ecosystems should yield knowledge that will further human progress on many fronts.

Forests and Water. The significance of forests to water supplies is commonly attributed to some direct effect of forests on the amount of rainfall. The magnitude of this effect remains in doubt, in part because only a few studies have been attempted and in part because of the difficulty of eliminating variability due to either place or time. Results suggest that any such effects are mostly local. The finding that much of the rainfall in the western Amazon Basin is water transpired by the forests to the windward (Villa Nova and others 1976) may suggest—but does not prove—that the rainfall would have been less had it been transpired from vegetation other than forests or evaporated from unforested areas.

Actually, the most important effect of forests on rainwater is its disposition once the rain reaches the forests. Part is intercepted by the forest canopy and evaporates. Interception by rain forest canopies varies widely with the density of the canopy and the intensity and duration of the rainfall. For short, light showers, all water may remain on and evaporate from a dense forest canopy. Measurements over time suggest that, under closed forests, about 15 to 20 percent of the rainwater is held in the canopy (Kline and others 1968, Lawson and others 1981). Whether such "lost" water benefits the ecosystem or not has been debated. Its evaporation cools the vegetation and the air, presumably reducing the draft on soil water for transpiration. Moist vegetation is darker in color than dry vegetation, and therefore absorbs more solar energy, suggesting that at least part of the energy required would not otherwise have been available for the ecosystem's needs (Satterlund 1972). Moreover, the diffusion of intercepted water requires less energy than transpiration.

In the Brazilian Amazon, studies have shown that 62 percent of the water goes to evapotranspiration, and 90 percent of this is due to a delicate energy balance (Villa Nova and others 1976). Because the hydrological cycle is so intimately related to the presence of forests, general deforestation can lead to serious consequences.

Litter that accumulates on the forest floor absorbs the physical impact of torrential downpours and releases the water gently to the mineral soil beneath (fig. 2–4). This "cushioning" action largely prevents the water from becoming turbid with suspended surface soil particles and thus clogging soil pores beneath. In addition, the decaying litter enriches the water entering the soil and supports organisms that produce porous upper soil layers. These processes are the most obvious ways forests enhance water supplies (fig. 2–5). The draft on soil water is greatest under forests with their deep-rooted trees and high rates of transpiration. Between storms porous forested soils again become highly receptive to new water.

Storm water, generally received in torrents, may carry away the litter and surface soil if it cannot promptly percolate into the soil. Such percolation generates the lifeblood of the Tropics. It supplies the forest above it, and it follows subterranean pathways to reappear gradually but continuously in springs that feed streams that in turn safeguard and support aquatic life, commerce, irrigation, and urban life downstream (fig. 2–6). It is this intimate relation between forests and usable water that makes the Tropics habitable. Thus, tropical forests provide soil protection, a high soil infiltration rate, and, where soil is deep, substantial detention storage (Pereira 1967).

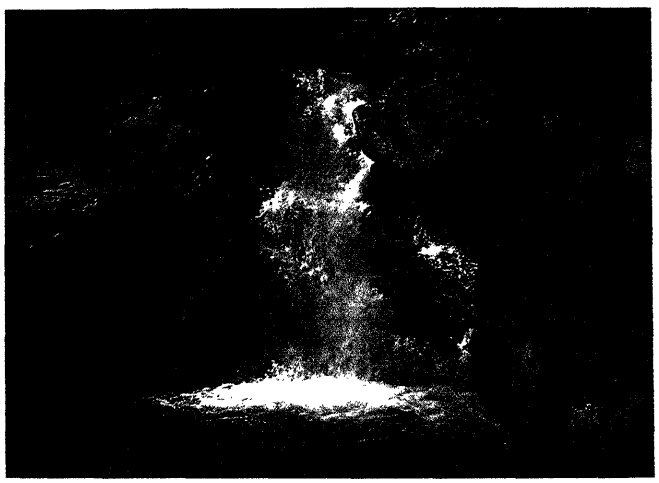

Figure 2–4.—*Forests have an unexcelled capacity to promote rainwater infiltration into the soil, ameliorating floods, and gradually releasing a constant flow that is free of sediments.*

Figure 2–5.—*The delayed release of rainwater from forested soils of the uplands maximizes the value of downstream water impoundments that are vital to urban centers.*

Even after water enters streams, it may continue to be affected by riparian forests. Tree growth on streambanks stabilizes the soil. When floods occur, the forest litter may support aquatic life important as a source of human food. Flooded streamside forests slow water movement, and thus precipitate sediments, capturing nutrients and building up the level of streambanks. At river mouths, estuaries, and along relatively protected seacoasts, mangrove forests retain sediments and provide habitats for important terrestrial, amphibious, and marine fauna.

Figure 2–6.—*Montane highway construction and deforestation immediately show the effectiveness of the former forest in preventing sedimentation of this river in Sarawak.*

Many rivers separate nations or run through more than one nation. Therefore, forest benefits to streamflow become an international concern and expand the self-interest of all nations into a web of interdependence.

Forests and Soil. The relations between forests and tropical soils are an outgrowth of forest-water relations. Humic acids picked up by rainwater as it passes through the forests accelerate weathering of parent rock and other soil-forming processes. The forest floor (by absorbing the shock of intense rainfall) and the dense and deep tree-root systems minimize landslides. Studies show the superiority of forest over other types of vegetative cover in this function (Lawson and others 1981).

The effectiveness of forests in controlling erosion varies with the climate, slope, soil condition, and the character of the forest. The densest forests, which permit few living plants in the ground layer, may be less protective than more open forests with herbs, grasses, or young trees to hold the litter in place on slopes or where floodwashing otherwise would occur. Trees that are excurrent in form, particularly palms, tend to concentrate throughfall as stemflow. As much as 10 percent of the rainfall may reach the soil beneath rain forests in this manner (Lawson and others 1981). This stemflow may be rich in particulates washed from the tree bark and thus provide nutrition at the base of the tree, but the concentrated flow downslope from that point can, in extreme cases, cause severe erosion. Where these problems become serious, they can be ameliorated by silvicultural practices.

Forests and Agriculture. It has already been pointed out that forests safeguard agriculture in the Tropics. In much of tropical America, the harvesting of wood from forests is an integral activity of farmers, providing products for either local consumption or distant markets. The employment provided by wood use and production is in tune with the traditions and needs of forest regions and essentially benefits rural people. Nearly all the soils capable of sustained (or even intermittent) agriculture are a heritage from forests, which have enabled soil building. The results are particularly impressive on the most productive agricultural soils of the region—valley bottom soils that are level, workable, and (at least initially) fertile. An example of the usefulness of such soils is to be seen in the floodable varzea in Amazonia, used to produce short-term crops (Sioli 1973). If these bottomlands are diked to reduce flood damage, they cease to receive the nutrients that formerly were supplied from forests and forest soils upstream (fig. 2–7). Thus, for continued cropping of such areas, canals must be constructed to introduce water that contains sediments (Sioli 1973).

Tropical forests benefit agriculture in other ways. They tend to be the only residual source of native varieties of food plants, not only those now in production but also many others that may eventually prove useful. These attributes are of growing value as the production of food, forage, and fiber must be intensified. Native varieties of plants are now being sought out, conserved, and bred into crops for anticipated advantages.

Mixed natural forests, unlike agricultural crops, are rarely subject to epidemics. Evolution and coevolution of hosts, predators, and parasites in primary forests long since have produced equilibria that minimize fluctuations in the populations of individual species within the systems. Lands formerly forested harbored organisms that could become pests when the land is farmed. But these forests also contained control mechanisms for these pests. However, if epidemics do occur, maximum use of biological controls is desirable, usually for financial as well as environmental reasons. Thus, the presence of native forests within agricultural regions may facilitate such controls and in that way foster food production. Unfortunately, optimal location, extent, shape, and management techniques for forests to provide biological controls for pests in nonforested areas are not yet known.

Forests adjacent to farm crops also harbor insects and other animal life vital to pollination of crop plants. Insects pollinate most cultivated vegetables, fruits, and flowers (Biswas and Biswas 1976).

The importance of forests as a source of soils for farming is nowhere more clearly demonstrated than in the shifting cultivation systems and related practices that keep alive almost the entire rural population of the Tropics, some 630 million people (fig. 2–8; Nair 1980). The essential element of shifting cultivation is that after a cropping period, the land is fallowed, generally in woody growth, for 1 to 20 years or more. During this period, the soil productivity for another cropping period is restored beneath a recovering forest, enabling farmers with little capital and only the most primitive tools to subsist on crops produced by soils whose fertility is depleted very rapidly (Watters 1971). The fallow period restores the soil partly through addition of nutrients from weathering and rainfall. In addition, the rapid development of secondary forests during the fallow period protects the formerly exposed soil from erosion, rapidly restores soil porosity, and captures nutrients that might otherwise leach out.

Figure 2–7.—*The most productive soils for agriculture were accumulated beneath former forests, and trees on the hills and borders continue to protect the environment for farming.*

Figure 2–8.—*Old-growth tropical forests are felled and commonly burned rather than harvested because they are remote from markets, and the purpose is not to obtain their wood but rather to use their soil for food production.*

Some of these nutrients are then made available to the next farm crop when the forest is felled and burned. The effectiveness of the practice is shown in the repeated cropping of some of the poorest soils of the Tropics, where slopes and physical and chemical soil properties do not favor continuous agriculture of any kind.

Artificially established tree crops, such as coffee (fig. 2–9), cocoa, oil palm, and rubber (fig. 2–10), have also improved and maintained productive soil conditions. Unlike conventional cultivated or pastured crops, these do not "wear out" the soil, at least not as quickly. Some areas have been in continuous production for 50 years or more. One practice has been to plant these crops under a tree overstory. The presence of a light tree cover (either tree corps or tree shade over other crops) fosters maintenance of the soil and constrains the development of understory crops to a level commensurate with available nutrients. Cultivating tree cover is a wise investment, because it may greatly lengthen the cropping period on land that would otherwise require fertilizers and costly soil-conservation measures.

These effects of forests on agriculture are not confined to the humid Tropics. In dry areas, tree corps may draw on moisture at depths below those used by food crops while their litterfall reduces evaporation of soil water near the surface. Litter also provides nutrients that may not otherwise be available at the surface. The use of a sparse tree layer (particularly legumes) over corps in dry areas is common.

Figure 2–9.—*Tree crops such as coffee commonly replace forests, and if well managed, may persist for many years.*

Figure 2–10.—*Tapping latex for rubber remains an important forest industry in tropical America.*

Forests as a Source of Products. Biologically, forests convert energy and nutrients into assimilate, a process termed "gross primary production." When respiration is deducted, the remaining growth in roots, stems, branches, and leaves is termed "net primary production." Net primary production in the tropical forests (above ground only) ranges up to 30 t/ha/yr (Anon. 1980e). Timber plantations, on the other hand, may yield up to 60 t/ha/yr (Oudshoorn 1974).

Wood is one of the most useful of the world's raw materials. It is versatile, widely available, and relatively low in cost. Compared to most alternative materials, wood is superior in its strength-to-weight ratio, more workable, and more attractive in appearance. It is also warm to the touch.

Manufacturing steel requires 87 times as much energy per tonne as does processing wood; aluminum, 45 times as much (Makhijani and Lichtenberg 1972). Moreover, wood products are biodegradable, presenting no major environmental disposal problems. Such advantages have led to wood consumption, at least formerly, roughly equal in weight to that of all metals, cement, and plastics combined, even in the United States (Cliff 1973).

Three broad categories of wood materials are used industrially: (1) solid wood not structurally altered, (2) fiber, the complex of cellulose in the walls of hollow cells, and (3) chemical components of cellulose, lignin, and extractives.

Worldwide production of wood products in 1992 was estimated at 3.477 billion m^3, an increase of 19 percent during the decade (Anon. 1993b). Of this 3.477 billion m^3, 380 million, or about 11 percent, were produced in tropical America, an increase of 20 percent during the decade (table 2–1). Of this increase, 74 percent was for fuelwood and charcoal, a proportion unchanged in the last decade. Exports of all forest products from the countries of the region in 1992 were valued at US $2.2 billion, up 126 percent in current dollar value.

Of the industrial products of the region, nonconiferous sawn wood production reached 13.9 million m^3, with exports worth US $215 million in 1992 (fig. 2–11). Of greater economic significance was paper and paperboard production, totalling 9.8 million t and exports valued at US $867 million. This is a 10-year increase in production of 40 percent and a fourfold increase in export value, in current dollars. Wood pulp production increased 56 percent to 6.1 million t in 1992, with exports worth US $698 million (table 2–1).

However, tropical America consumes more sawn wood, veneer, and plywood than it produces. In 1982, the developing countries of America produced only 3 percent of all wood exported from such countries worldwide and a negligible portion of the sawlogs and veneer logs, but 19 percent of the sawn wood and 34 percent of the veneer sheets (fig. 2–12; Anon. 1984a).

The leader in the production of fiber products in the American Tropics has traditionally been Brazil. This country produced 2,900,000 t of pulp and 3,200,000 t of paper in 1982 and 6,100,000 t of pulp and 9,800,000 t of paper in 1992 (Anon. 1993b).

An indication of the economic significance of tropical forests is the record of the Indian Forest Service, which historically has been one of the most effective public forestry agencies in the world. This agency is concerned with many forms of public assistance other than the mere sale of timber; nevertheless, between 1950 and 1960, it yielded revenues more than 50 percent greater than its expenditures (Anon. 1960d).

Forest production, as defined here, reflects the harvest of much old-growth timber, which is a natural heritage rather than a product of human effort (fig. 2–13). This heritage is being eroded in many places. However, with management and culture, continued production is not only possible but in some places has already been remarkably successful.

Table 2–1.—Production and export of wood products in tropical America, 1982–92

Wood product	Production		Exports	
	1982	1992	1982	1992
	Thousand m^3		Thousand US$	
Roundwood	316,500	379,900	—[a]	—[a]
Fuelwood/charcoal	233,200	280,400	—[a]	—[a]
Processed products	—[b]	—[b]	977,500	2,214,600
Sawn wood (nonconiferous)	13,100	13,900	202,300	214,900
Wood-based panels	3,900	4,100	179,100	279,700
Veneer sheets	300	400	59,500	52,900
Plywood	1,500	1,500	62,800	127,300
	Thousand tonnes			
Wood pulp	3,900	6,100	278,500	698,100
Paper and paperboard	7,000	9,800	216,700	866,900

Source: Anon. 1993a.
[a]Information not available.
[b]Units not additive.

Figure 2–11.—*Timber from tropical lowlands is largely extracted by rivers as is seen in Panama.*

The development of processes that use mixed tropical woods in the manufacture of pulp and paper has already reduced tropical America's imports of these costly forest products. The problems that remain in expanding cellulose use are more economical than technical (Kyrklund and Erfurth 1976). One prospect is more complete utilization of natural stands. Another is that the faster growing, lighter woods of the region's natural regeneration may prove as good as (or better than) the mix from first cuttings in natural stands for pulp. The feasibility of plantations in most parts of the region depends largely on cellulose markets for intermediate-sized thinnings or for short-rotation crops.

Next to the soils, the water they conserve, and the nutrients they hold, the most important commodity of tropical forests certainly has been fuel. More than 1.5 billion people worldwide depend on wood for cooking and warmth (Anon. 1977b). It is estimated that in Latin America wood consumption for fuel ranges from 0.36 to 1.03 cubic meters per person per year (Arnold and Jongma 1979). In 1974, this meant a total of 240 million m^3, one-eighth of the world's total consumption of fuel wood. This amount was 82 percent of the wood consumed for all purposes within the region (Arnold 1978). Wood provided 20 percent of Latin America's entire energy consumption in 1974. The developing countries collectively have untapped energy potential in their forests, which, if managed well, might supply all their energy requirements and provide a surplus for export (Earl 1975). An early prediction that, if only 5 percent of the deforested land in developing countries were planted to rapidly growing tree species, the world would have no risk of wood scarcity may still be valid because deforested land may be increasing as rapidly as wood needs (Sartorius and Henle 1968).

Wood is principally cellulose and lignocellulose, made up of about 50 percent carbon (C), 6 percent hydrogen

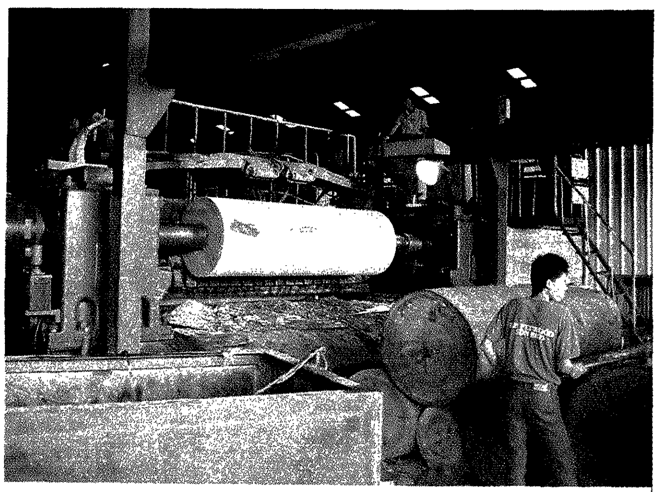

Figure 2–12.—*The large trees with attractive, medium-weight woods provide one of the most valuable products of tropical forests, veneer, being made here from a dipterocarp in Sarawak.*

Figure 2–13.—*The harvest of tropical timber typically is concerned solely with immediate profit, at the expense of any immature trees that might provide future crops.*

(H), and 44 percent oxygen (O) (Earl 1975). Its calorific value is 4.7 kcal/t oven-dried and 3.5 air-dried. There is remarkably little variation among species. In comparison, calorific values are 6.9 kcal/t for bituminous coal and 9.8 for fuel oil.

Wood is the cheapest fuel available in most of the region. No storage is required, yet, it can be stored for a long period. Its production is labor intensive, which may or may not be an advantage. Its removal can be so complete as to deplete forests, requiring management discipline. Its bulk is great, a problem in transportation and storage (Earl 1975).

An analysis of the fuelwood situation some years ago in tropical America showed the following areas to be experiencing acute shortages: Haiti, eastern Brazil, El Salvador, coastal Peru, and the Bolivian altiplano (Anon. 1981f). Less critical deficits existed in northern Mexico, Honduras, Cuba, Jamaica, Dominican Republic, the Andean slopes from Colombia to Bolivia, and Trinidad.

In extensive deforested areas in the Eastern Hemisphere, fuelwood production in forest plantations has proved successful. A favorite species is *Casuarina equisetifolia,* a tree of rapid growth and dense wood. In Madras, India, this tree, on a 4-year rotation, yields 200 to 250 t/ha of dry wood (Kaul and Gurumurti 1981). In Dahomey, now Benin, the fuel needs of a dense population in a poorly forested region have been supplied by plantations of *C. equisetifolia* along the seacoast (Buffe 1962).

Future demand for wood fuel seems assured because satisfactory substitutes are generally lacking. One foreseen development is greater efficiency in fuelwood use. Cooking in the open consumes five times as much fuel as cooking in an enclosed stove (Arnold and Jongma 1979). Simple improvements in stove design may save yet another 70 percent. Another option is conversion of wood waste to charcoal. Fuelwood plantations, successful for decades in India and elsewhere, can also concentrate production and succeed if they are in keeping with the traditions and knowledge of the people.

The inflexibility of fuelwood markets is to be seen in heavily populated India, where 80 percent of the rural energy requirement is still met from noncommercial sources. Of this amount, 64 percent is firewood, used mostly for cooking. In fuel-scarce areas, fuelwood plantations are preferable to any substitute forest crop. The consumption, about 0.6 tonne per person annually, is at least as great as in much more heavily forested tropical America (Kaul and Gurumurti 1981). Cooking rice in India has cost about 17.5 percent of the food energy content of the rice itself (Revelle 1981).

Charcoal derived from wood has a calorific value of 7.1 kcal/t, comparable to coal (Earl 1975). It burns almost smokelessly, and much of its energy is emitted as radiant heat. Its low bulk density makes it fragile and necessitates special transportation and storage. A danger of carbon monoxide poisoning exists from its use in confined areas (Earl 1975). Nevertheless, charcoal is a common fuel in the region's urban areas. It is used industrially in the region as well.

Charcoal manufacture is particularly suited to rural tropical society. It may be pursued profitably on a small scale. The ratio of capital to labor is low, so it creates more employment than most industries. It utilizes common skills and requires little managerial or supervisory expertise. Its rural location contributes to the urban/rural economic balance (Earl 1975).

Wood from forests will be at least as important to the Tropics in the future as it has been in the past. Forested tropical countries are importing timber products, but the developed world may soon have little wood to export to them. The demand for all types of wood, including that suitable for such uses as fuel and chemical feedstocks, can be expected to increase in developed countries. Countries with abundant raw-material stockpiles can be expected to move into a better bargaining position (Mitchell 1978). Substitution of other materials is not likely because there is not enough cheap energy to make substitutes. Between 1980 and 2000, the demand for products from tropical woods was predicted to increase 110 percent worldwide, 180 percent within the Tropics, and 220 percent in tropical America (Pringle 1976).

Consequences of Overuse. Overexploitation of tropical forests is common, primarily because of the tradition of free use. Where forests are plentiful, their profligate use has been neither illegal nor locally recognized as wasteful (Hardin 1968). Established use traditions become thought of as rights, generally before either the public or government foresees ultimate disaster.

Overexploitation is serious because tropical forests are intrinsically fragile. Outwardly, forests on moist sites show remarkable powers of recovery from disturbances, rapidly regenerating in fields left after cultivation and closing gaps in the tree canopy. Forests subjected to selective logging or infrequent shifting cultivation may not change sharply in general appearance. In a quantitative sense, they may appear to endure well even what appears to be abusive treatment. Their complexity, however, results from a web of interdependence among components that have coevolved. Disturbing the delicate balances among organisms, even by cautious, selective harvesting might eventually so simplify the ecosystem as to deteriorate its stability and reduce its capacity for self-restoration. In the pure sense, primary tropical ecosystems, once substantially modified, are thought not to be retrievable (Gomez-Pompa and Vazques-Yanes 1972). Even if a long subsequent period of complete protection were afforded, long-term changes in climate and other influences could be expected to preclude restoration of an essentially identical primary forest.

One of the subtlest consequences of human intervention in tropical forests is the gradual loss of biodiversity. This might result for example, from direct harvesting of all mature (seedbearing) *Cedrela* trees or mature game animals. Even more subtle would be the deterioration of habitats or inadvertent favoring of enemies of certain species. Because habitat requirements, parasitism, and predation are not well understood, such damage may be undetected. If as many as 10,000 individuals may be needed to conserve the gene spectrum of a species (Poore 1976a), obviously the decline of a species, particularly one sparsely distributed, might be indiscernible until long after its population falls below that level.

The effect of wood removal on diversity cannot be measured purely in terms of changes in the number of plant species. Animal species may be strongly affected by some plants that biologists recognize as ecological "keystones." Keystone plant species may provide food for animals during periods when other, preferred foods are not available. Evidence indicates that as little as 1 percent of the plant species might tide over most of the fruit-eating wildlife of moist forests, suggesting that timber removal geared to conserve certain keystone species might not reduce the capacity of the forest to feed many forms of wildlife. It remains to be seen, however, whether the keystone species, if their proportion of the forest increased, could be safe from pests and diseases, and if other requirements of animal populations, such as reproductive habitat, would persist regardless of how the rest of the forest was treated.

Another, more apparent consequence of overexploitation is a decline in the forest's capacity to produce marketable timber through removal of the best timber trees and damage to those remaining. Usually, harvesting also results in erosion from abandoned, unstabilized roads and skid trails. Continual overexploitation reduces wood yields for both exports and local needs.

The overuse of forests is readily evident where cultivators so rapidly deteriorate the soil that they cannot recrop the area within a reasonable period. On parts of the terra firme (upper terrace) of the Amazon, for example, cultivation for 2 years followed by a 10-year fallow period permits only one more traditional crop (Sioli 1973). Cropping decreases soil infiltration, reducing the recharge of soil water and increasing floodflow. Erosion and landslides may result. Overuse of forest land has in some areas progressively shortened the fallow period to a point where fallowing suffices neither to restore soil fertility nor to regenerate a usable forest crop (Anon. 1977b). Restoration is then seen as impractical, so the people either have to leave or continue a marginal existence. The ultimate result can be a vast, unproductive waste. Such conditions are forerunners of famine, epidemic disease, and civil strife, examples of which already exist in Africa and elsewhere (Poore 1976b).

In central Tanzania, gathering fuelwood for an average family now occupies 250 to 300 days a year of one person's time (Anon. 1977b). An extreme situation is in the Punjab of India where only 1 percent of the demand for firewood can be met by local forests. Under these conditions, the rural people, although fully aware of the impact on food production, are forced to use dung, maize stalks, and other agricultural residues for cooking fuel (Sagreiya 1946a, Singh and Randev 1975).

As recent world events illustrate, the consequences of extensive deforestation may be far reaching. The desertification underway in Africa south of the Sahara is thought to emanate from brush fires, branch lopping for forage, deforestation, overgrazing, and trampling of vegetation by animals (Delwaulle 1973). It has resulted in deterioration of the remaining natural vegetation and crop yields. This, in turn, has led to mass migration of the inhabitants.

Land: Forest Versus Nonforest

Setting rational goals for forest land use calls first for consideration of the priorities and requirements of nonforest land uses and then an assessment of the several major forest uses. A schematic diagram for the identification of forest and nonforest land and its development is seen in figure 2–14.

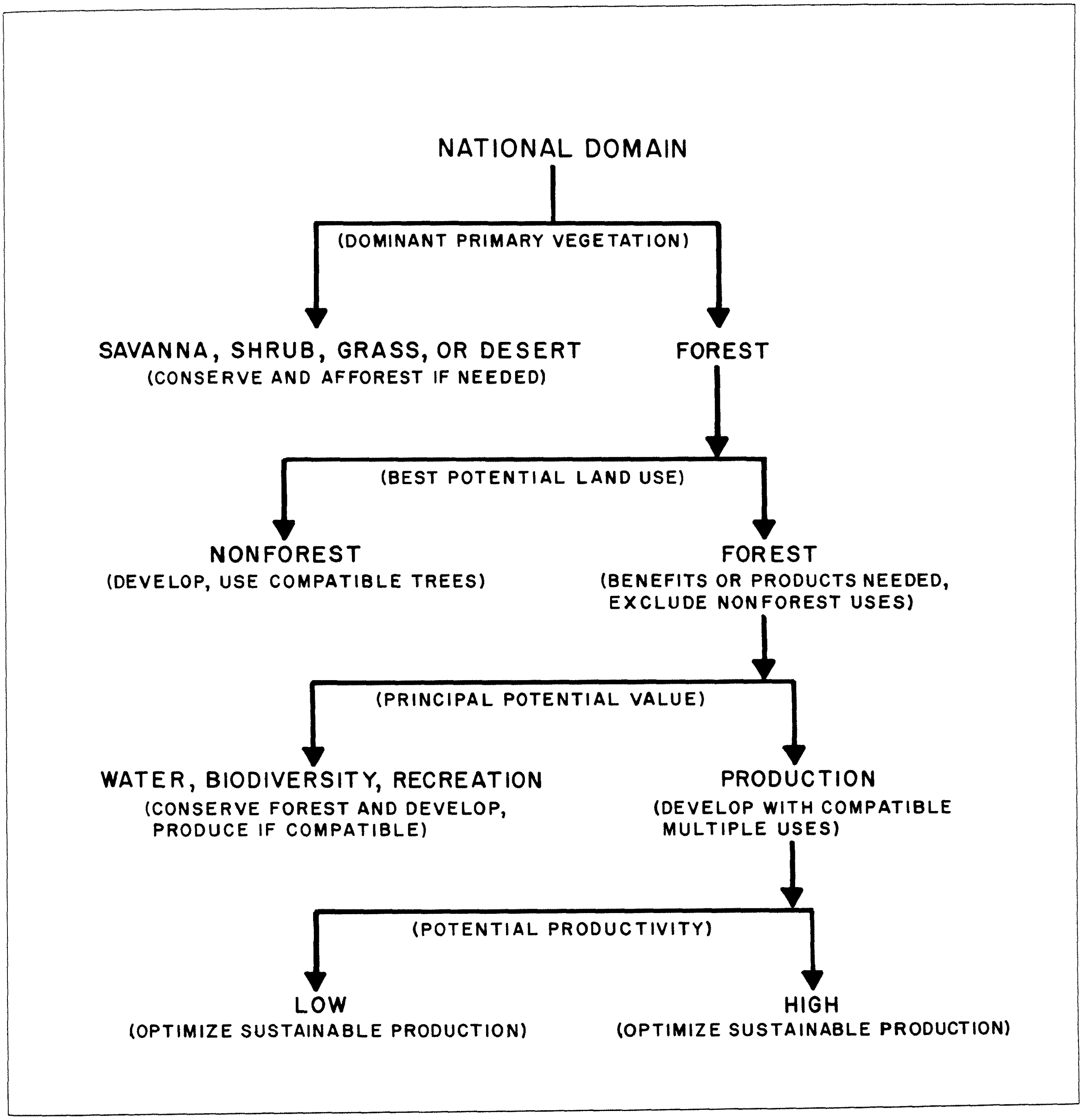

Figure 2–14.—*Schematic sequence for the identification and treatment of lands for trees and forests.*

Forest Versus Agriculture. Food production offers more obvious and earlier returns than does forest production. Population growth is not everywhere being matched by increases in food production, as seen in table 2–2 (Anon. 1993b).

A consequence of this trend is continued deforestation to exploit the soil and the plant nutrients recycled from the forest vegetation. The population agriculturally active in the region increased between 1980 and 1982 by more than 2 million persons (Anon. 1993b). Land dedicated to permanent and temporary agriculture increased by more than 65 million ha between 1970 and 1991 (Anon. 1993b). Irrigated agriculture, mostly dependent on forest water, increased some 2 million ha between 1981 and 1991.

The hardest part in securing land for long-term forest production is protecting it from food and forage production. Forests grow best on land that is also the most productive for food and forage. Yet, the deforestation of this land for farming may appear necessary even where the farming practices themselves may not have been successful or lasting.

Any comparison between food or forage crops and wood crops is usually biased against forests because agricultural values are both tangible and immediate, whereas many forest values are not. Moreover, agricultural research has led to intensification of production methods that have no equal in forest production. Unlike the farmer's field, forests contain many poor quality or unmarketable trees and generally none that have been improved genetically. Forest stocking is not precisely controlled; neither are nutrient supplies, weeds, insects, or diseases. If agriculture had these handicaps, it would not be economically attractive either. Correcting these deficiencies in the culture of coffee, a tree crop, increased yields in Puerto Rico at least twelvefold (Wadsworth 1962). Cassava yields on red-yellow Podzolic soils of the humid Tropics, have been increased nearly 60 percent purely by a modest application of NPK fertilizer, and soil properties were improved as well (McIntosh and others 1980).

Food production is declining in more than half the countries of tropical America (Anon. 1993b). Therefore, there are strong arguments that level, well-watered land with deep, workable soils should be used for food and forage production. However, if all such land were managed at top productivity and fully protected from wide fluctuations in river flows by forests in the uplands, most countries could produce most of their needed food and forage and still dedicate large areas to wood production and other forest benefits.

Unfortunately, the best soils of the region are not fully productive. Consequently, less suitable land has been pressed into service. Because the nutrients contained within the trees are released when they are felled, soils

Table 2–2.—Food production in tropical America, 1972–81

Country	Per capita food production index	Country	Per capita food production index
Brazil	115	Guatemala	92
Bolivia	114	Honduras	91
El Salvador	112	Peru	90
Colombia	110	Panama	84
Ecuador	110	Dominican Republic	84
Jamaica	110	Suriname	83
Mexico	101	Cuba	81
Venezuela	99	Guyana	68
Paraguay	94	Haiti	67
Costa Rica	93	Nicaragua	62

Source: Anon. 1993a

Note: Per capita food production index in 1969–71 was 100.

too poor for continuous cultivation can still be so used temporarily (fig. 2–15). The area of such marginal land required to sustain a given yield is far greater than that in use at any one time, because, after one or two crops, the land must be fallowed for several years before it can be recropped. But in mountainous areas, severe erosion resulting from this practice may ultimately preclude even tree crops. In Cuba, for example, a country largely forested when "discovered," conversion to agriculture has left only 16 percent of the island forested in 1990 (Anon. 1993a). More than 80 percent of the island of Puerto Rico was deforested for the same purpose (Murphy 1916). Without special incentives, farmers hesitate to adopt practices that would allow continuous field cultivation even where fallowing has obviously been degraded by reducing its period and where the advanced technology has already been developed and proven (Ward and Cleghorn 1964).

The prospect of greater financial returns from the production of food and forage than from timber on the best land has led to widespread deforestation in the Tropics, much of it a result of deliberate colonization and rural development schemes. Such schemes are usually successful in deforestation but less so in providing continuous support for settlers from farming. The result on extensive areas is the near abandonment of land that was once covered by luxuriant forests. This record justifies not relinquishing to agricultural exploitation all forested land that superficially appears suited to it. Intensifying agriculture on land already deforested would be more rational.

Figure 2–15.—*Recently deforested slopes in Sarawak are commonly converted to plantations of black pepper vines, a cash crop.*

In most cases, the amount of forest destroyed and the density of the rural population are directly related (Poore 1983). Urbanization is apparently associated with less deforestation. In areas with low population densities, such as the central Amazon, the forest is less threatened than in more densely populated Central America. South Asia is seen as a hopeful exception. There intensive forest management, community forestry, and high-quality intensive agriculture allow a denser rural population to be supported with less forest destruction.

Holdridge (1959) points to climatic features that limit food and forage production more than wood production. He concludes that agriculture is most successful where rainfall and evapotranspiration are about equal, in the "moist" and "dry" life zones as opposed to the "wet" and "very dry" zones (appendix B). He says that in the wet zone, fertility is hard to maintain because of leaching and erosion. In the very dry zone, water becomes limiting. He points out that shifting cultivation is possible where permanent agriculture is not, but that it may yield too little to support permanent communities.

Tosi (1975) considers Holdridge's moist forest life zone optimal for agriculture and animal husbandry. However, even here, dry seasons may range up to 7 months, and a dry period of only 2 to 4 months is enough to cause moisture deficiency in unirrigated field crops and pasture grasses. Tosi further points out that in the wet forest and rain forest life zones, water surpluses are so great that leaching drastically reduces soil fertility. Even pasturing is low in productivity because of livestock treading on waterlogged soils. In the generally well-watered Amazon, rice and corn culture is questionable because they rely heavily on capital and machine inputs in an area of unskilled farmers (Smith 1978). The multilayered polyculture of 13 species of plants used by the Caribs under these conditions is less risky (Smith 1978). However, it presents no prospective supply of products adequate for urban markets.

On poor land, the advantages of trees over other crops become overwhelming, a fact especially apparent where poor soils result in low yields and short cropping cycles. Permanent tree crops are recognized by some agricultural experts (Alvim 1981) to be most appropriate where rainfall is high and soils are poor. Their most important ecological advantage over annual crops is their protective value.

Alvim (1981) also pointed out that tree crops demand fewer soil nutrients and tolerate greater soil acidity and aluminum toxicity than farm crops. Their lower nutrient demand, he said, not only seems due to mineral recycling—a function that annual plants cannot perform efficiently—but also to the fact that the products harvested from perennial crops usually have a lower nutrient content than those from annual crops.

Alvim listed only five perennial agricultural crops that can be recommended as appropriate for the Amazon Basin: rubber, oil palm, cacao, sugar cane, and black pepper. Other tree crops that might be considered include guarana, achiote, palm fruits, palm hearts, and copaiba timber. Alvim believes that the potential land requirements for all of these would be perhaps 1 percent of the basin, leaving nearly all the area for timber crops. Perennial crops, however, in leading to fragmentation of land use, may pose a far more serious danger to the security of forests than subsistence farming and annual crops (Gordon 1961).

On marginal land, wood production differs from grazing in the following ways: (1) it requires more capital per unit of labor and land area, (2) it produces a greater revenue per unit of area, (3) it employs more persons per land unit, and (4) it is more sensitive to the rates of interest charged on capital (Johnston 1966).

Pasture management on the poor soils of the moist Tropics has been questioned. Simulation tests of yield prospects in the Amazon Valley led to doubts that any of the systems popular or promoted at present can assure sustainable yields (Fearnside 1979b). In drier climates, pasturing is not only marginal but may irreversibly set back the forest, as 1.7 million ha of lalang grass in Indonesia resulting from forest burning will attest. Reforestation of such areas has proved difficult.

On land best suited for agriculture or other land that must be used for food crops, there may still remain some out-of-the-way places where productive forests can be grown. As an example, in the Punjab, where 80 percent of the land is farmed, 4 percent is forested (Singh and Randev 1975). This area, totaling 100,000 ha, includes 42,000 ha in narrow strips along railway lines, roads, drains, and canals. Another 22,000 ha are in small blocks along rivers. The remaining 36,000 ha are scattered over plains and hilly areas. More than half of this forest land is preserved for its protective value only. Only 0.15 ha per capita is available to produce wood for human use.

The relentless invasion of shifting cultivation and pasturing into forests on progressively less stable and less productive soils has been accompanied by growing human misery and loss of future productivity of the land for agriculture and possibly also for forests (fig. 2–16). As a consequence, the search has begun for alternatives that will assure sustainable yields. Studies under what may be favorable conditions in central Brazil (Watters 1974) have shown that a village of 145 people that had not moved for 90 years required 5,500 ha of forest, or 38 ha per capita. Cultivating in the forest may require less labor to produce a specific unit of food than cultivating grassland soils or operating a permanent field system of agriculture (Ward and Cleghorn 1964). However, land for forests may no longer be available to this extent in most of the Tropics.

One suggested alternative, termed "agroforestry," includes growing farm and forest crops concurrently or alternately on the same land, the subject of chapter 8. Concurrent crop integration includes the already extensive and time-tested plantations of coffee, cocoa, and fruits under tree shade and the use of such conventional tree crops as rubber, oil palm, and coconuts over food or forage crops, including tree fodder. Good management

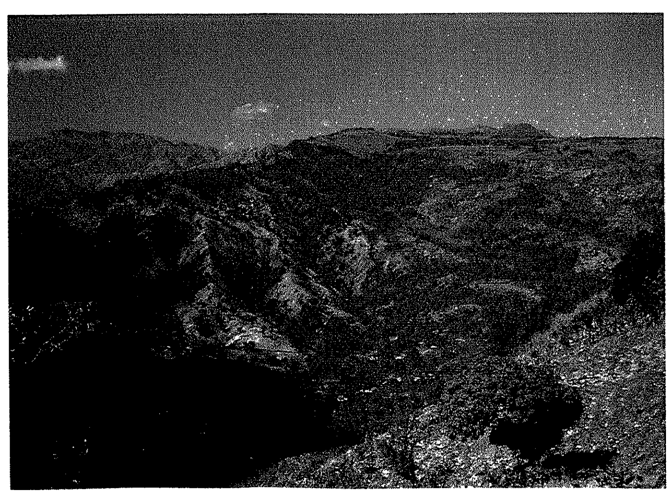

Figure 2–16.—*Extreme overuse of formerly forested slopes produces degraded land such as is seen here in Haiti.*

of a tree story over food or forage crops may help stabilize agricultural production by lengthening or augmenting the productivity of the cropping period or reducing the length of the fallow. Even small gains of this nature should prove popular with farmers and reduce the need for felling more natural forests. A secondary gain could be the production of wood from the trees.

Sequentially integrating farm crops with wood is the century-old taungya system of starting timber plantations by initial intercropping with food plants. Such plantations may be primarily for tree crops other than wood and may or may not be so spaced as to permit continued farming or forage production beneath the trees, depending upon the site's potential for the two types of crops.

Agroforestry is especially useful for land otherwise marginal for agriculture. Some 49 million km^2 of land in the Tropics (65 percent of the total) was said to be in a "wasted" condition in 1979 (King 1979a). About 630 million people (35 percent of the total population of the developing countries) depend on this land for subsistence. Agroforestry is a means to produce both food and wood from such land.

In identifying land to be dedicated to forest production, agroforestry could be of great significance. Agroforestry does not promise all the benefits of closed forests, but if stable agroforestry could replace shifting cultivation, it could clarify the boundaries between closed forests and farms. Even if it were to employ all 630 million people, agroforestry would undoubtedly prove most rewarding on the better "waste" lands, so secondary forests might remain as such. Tosi (1975) warned that new settlement should be confined almost totally to the humid (moist forest) zones; only under special soil conditions would perhumid (wet) areas be suitable for sustained agriculture or grazing.

The volume and quality of wood that might be produced by agroforestry are unpredictable at this early stage of experimentation. Sources of uncertainty include site adaptability and yields of timber species under agroforestry (as opposed to pure timber production), the significance (if any) of fruit trees in meeting wood requirements, and the fact that agroforestry will be accepted by those who apply it only if wood remains a by-product of food or forage production.

Land-Use Capabilities. The selection of land for forest production should be based on the properties of the land itself and the requirements of different land uses. A first step in good land-use planning is the development and application of a system of land evaluation. Young (1976) specified that such a system should do the following:

- Evaluate land for specified uses
- Consider alternative uses that are physically possible and economically and socially beneficial
- Take into account both production and other benefits and inputs or necessary costs
- Consider environmental effects
- Permit evaluation in stages, according to the purposes and intensities of surveys
- Be versatile, applicable to both large and small land areas
- Produce permanent results, not unduly affected by current economics
- Permit revision
- Present results simply to inspire confidence from the nonspecialist.

Poore (1976b) said success in land-use planning depends on recognizing public interests and ranking them skillfully. Resolving conflicts is essentially political. He recommended a logical sequence of steps in planning: (1) identify the main areas of public interest, (2) examine land in relation to its importance to each of these areas, (3) compare values, and (4) settle conflicts. He pointed out that the test of any action should be its lasting effect on human well-being. He sees two complications in assessing effects: (1) many of these effects take time to become evident and (2) the effects may take place far from the point of cause.

The development and application of land-evaluation systems in tropical America are in their infancy. The climatic, physiographic, and edaphic parameters basic to land-use decisionmaking are not mapped everywhere and are not generally well understood. Mapped data have been the basis of most land-use allocation proposals in the region. Moreover, land evaluation and planning are long-term processes that generally can be done only in stages. But there is great pressure to make decisions quickly to meet immediate needs. Such has been the case in the Temperate Zone as well. Therefore, Young's (1976) provision that the planning system allow for revision as new information becomes available is of critical importance.

Two types of criteria are used in land-use planning: (1) those that are physical and essentially constant and (2) those that are social and subject to change over time. Specific criteria to help determine whether land should be dedicated to forest production and, if so, the benefits or products most appropriate include the following:

- The physical environment
  - —Climate—particularly the quantity and uniformity of rainfall
  - —Soil—particularly its depth (water-holding capacity) and susceptibility to erosion
  - —Physiography—particularly scenic values, slope, contribution to potential water use or floods downstream, and accessibility
  - —Presence and quality of existing forests and features comparatively scarce elsewhere.
- The prospective social environment
  - —Traditional land-use pattern and practices
  - —Prospective need for forest benefits, including those of both the adjacent population and tourists
  - —Prospective human pressures on the land for food production, on downstream water, and on the wood supply, including export prospects.

Applying one of the above criteria, Holdridge (1959), as has been pointed out, observed that rainfed agriculture is most successful where rainfall and potential evapotranspiration are about equal. Dubois (1971) applied another when he based his recommendation for the production of annual crops, perennial crops, pasture, rubber, cacao, oil palms, and timber or for shifting cultivation on the severity and periodicity of flooding in the Amazon Valley. Holdridge (1976), on the basis of foreseeable social pressures, listed land in Costa Rica most likely to lose its forests as: (1) fertile alluvial plains subject to no dry season (the Caribbean lowlands), (2) fertile arable land with a long dry season, and (3) mountainous land on the Pacific slope subject to drought and fire.

Plath and van der Steenis (1968), using available data on climate, soils, and slopes, classified land capabilities in Central America (table 2–3). From this tabulation, it is apparent that only 38 percent of the land should be

Table 2–3.—Land capabilities in Central America

Land-use category	Area (million km^2)	(%)
Suited for sustainable agriculture		
Most favorable climate		
(tropical humid)		
Intensive cropping		
Annuals	16	3
Perennials	4	1
Subtotal	20	4
Extensive cropping		
Annuals	6	1
Perennials	38	8
With trees	24	5
Subtotal	68	14
Total	**88**	**88**
Less favorable climates	103	20
Total (suited for agriculture)	**191**	**38**
Unsuited for sustainable agriculture		
(mostly suited for forests)		
Climatically	115	23
Otherwise	193	39
Total	**308**	**62**
Total land area	**499**	**100**

Source: Plath and van der Steenis 1968.

farmed. The rest includes areas that may be needed for residential, commercial, and industrial purposes, but most of the area would best be left forested. Plath's category for "extensive cultivation" in humid areas would appear to correspond to those areas where shifting cultivation is sustainable. The portion of the subregion now subject to shifting cultivation is certainly much more extensive than this, covering a large area of the land classed as unsuitable for agriculture.

The agricultural land capability classification system of the U.S. Soil Conservation Service (Norton 1939) has been tested in tropical America. The system is based on soil productivity, drainage, and erodibility. A study of the Andean region and part of the Amazon and Orinoco Basins in Colombia (Cortes 1977) showed only 20 percent of the land suited for annual crops. An additional 30 percent was land either level or gently sloping with poor drainage or land that was excessively stony, steep, or erodible. This left 50 percent of the land suitable only for forests, native pastures, and other natural vegetation to protect watersheds and wildlife.

McKenzie (1976) estimated that 5 percent of Venezuela's land is suited for annual crops, 32 percent for pastures, and 62 percent for managed forests. Independently, Luna (1976) concluded that 39 percent of the country should remain in forests. Of this amount, 31 percent (12 percent of the country) should be kept primarily for its noncommodity benefits and 69 percent (27 percent of the country) for wood production.

In 1978, Kudela estimated that 25 percent of Cuba should remain forested (only 13 percent was then so covered). In Puerto Rico, half the total land area has been recommended for forest (table 2–4; Birdsey and Weaver 1982, Wadsworth and Schubert 1977).

A common conclusion reached by these studies of land-use capabilities is that important areas that should be left forested have been or are being deforested and either overused or abandoned. The disparity between the ideal identified by these studies and reality should not relegate such studies to oblivion. There are important benefits from knowing what is desirable. Even where increasing population is making the disparity worse, it may be possible to direct degradation to land where the least resources are at stake and to restore forests where such land has been abandoned after clearing. Reforestation can be focused on areas where maximum aggregate values will accrue.

An important feature of the Puerto Rico study was identifying land where there is least controversy between government development agencies and landowners as to its use. Another was a liberal allowance for infrastructural (urban, industrial, and commercial) land-use expansion. Fortunately, this generous allowance proved to be minor relative to the entire land area. Finally, the allocation made to farming was limited by a realistic assessment of prospective markets for crops, so there remains on this heavily populated island a large area available potentially for forests. Theoretically, more than a quarter of the island is available for noncommodity benefits and yet is still able to satisfy, with proven technology, well over half the demand for forest products projected 25 years hence.

Land-Use Control. The long period generally needed to produce forests and forest crops requires that investments be made where they will not be lost through arbitrary changes in land use. The social and intangible nature of forest benefits justifies government participation to foster this stability. The well-being of entire nations and their cultures are at stake. The people as a whole have a clear

Table 2–4.—Prospective land use in Puerto Rico

Land-use category	Highest sustainable use	Land area (thousand km²)	Land area (%)
Urban	Residential, industrial, commercial	100	
Agricultural cropland	Food and forage cropping	345	
Other rural land			
Mangroves, swamps	Protective forests	10	1
Rainfall >250 cm/yr	Protective forests	43	5
Rainfall 100–250 cm/yr			
Slope >60%	Protective forests	68	8
Slope <60%	Productive and protective forests	202	23
Rainfall <100 cm/yr	Protective forests	122	13
Subtotal		**445**	
Total		**890**	**1**
Summary of forest use			
Protective only		243	27
Protective and productive		202	23

right and responsibility to participate in decisions affecting the future of their nation's forests.

A logical outgrowth of this philosophy has been public reservation of forests, particularly those valued for more than their immediately exploitable wood resources. Forests have been reserved in most tropical countries of the world, including those of tropical America. In west Africa, for example, between 1929 and 1950, more than 600 forest reserves were set aside in 9 countries, totaling 146,000 km^2, or 2.4 percent of the land area (Bellouard 1952).

However, Gordon (1961) has warned of the dangers of legally reserving forested land that later proves to be better suited to production of food or forage. He points out that forest land reservation and protection have generally been left up to governmental forestry agencies. He concluded that foresters may be deluding themselves if they believe that most of the land reserved in the past for forestry is going to remain so dedicated in the future.

The problems inherent in reservation in advance of social conviction are illustrated by experience in Venezuela. In the western Llanos, some 9,370 km^2 of forest was reserved in 1950 (Veillon 1977). Because much of the land is flat and seasonally well watered, it has been increasingly subject to trespass for cultivation and grazing (Luna 1973). Government efforts to control this practice without engendering hostility have not been effective. The State has had to allot part of one reserve for agriculture. Trespassers were allowed to sell their crops and new violations continued. The Turen Reserve was almost gone by 1973 (Luna 1973). The total reserved forests had, by 1975, declined by one-third to 6,270 km^2 (Veillon 1977). Yet, more than half of the deforestation has been in the premontane zone where protection of headwaters for rivers is needed. It was then predicted that about half the forests remaining in the reserve would be gone by the year 2000 (Veillon 1977). In tropical America, the wet and moist forest remaining in 1992 was estimated at 6.80 million km^2, a reduction of 22 percent from the original 8.73 million km^2 (Anon. 1993b).

In summary, forest land, if defined as land that should be dedicated to forests regardless of whether or not it is presently forested, constitutes an important part of every country in tropical America. This includes all land capable of growing forests that is not needed now or in the near future for other purposes. In most countries, deforestation, rational and irrational, is leaving forests only on land that must remain forested for reasons other than their wood productivity, such as the following:

- Areas incapable of serving other purposes
- Spectacular scenic areas already in use for recreation or tourism
- Rainy, steep, upper watersheds, particularly where existing water use is crucial
- Floodable areas, tidal coasts, and thorn woodlands.

Collectively, these forests may not be sufficiently extensive or productive to supply needed products (nor should they necessarily all be so used). To the degree that they can provide forest benefits, they constitute an environment that may be stable, because their continuation as forests may be required for more than one purpose. But because these areas tend to be marginal for forest production as well as for agriculture, additional land may be required for forest commodities. More favorable land then merits research to determine its potential forest yields.

Public reservation of forests does not guarantee forest production. Past reservations in the region commonly have been unprotected, forgotten, and lost. Much land best suited to forests is privately owned, occupied, and too costly for the government to acquire. So incentives are needed if private landowners are to conserve, manage, or reforest appropriate land. Such incentives must assure continued forest production. This objective can be partly met using forests intermixed with farmlands. Crucial to success will be good prospective markets and a public extension effort to involve landowners and rural communities.

Forest Land: Use Allocation

The intensified management prerequisite to increased and sustained production of forests should result in many benefits other than increased product yield. Intensive culture and plantation management require technical skill, and most of the earnings can go into the pockets of rural dwellers, counteracting the drift of people to towns. Likewise, much of the wood processing can be left to intermediate technology within the rural areas. A study in Australia showed that employment in the logging and sawmilling of plantation products provided continuous employment for 6 to 26 persons per 10,000 m^3 of product (Greig 1979). For administration and service to forest recreationists alone, 4 to 7 persons are employed per 100,000 visitor-days. Worldwide, the harvesting and processing of industrial wood and related silviculture plus peripheral services supported some 75 million persons in 1963 (Sartorius and Henle 1968).

Managing productive forests in the future will be progressively more complex, concerned with the conservation of natural ecosystems, species survival, a favorable flux of energy and materials and organic turnover, landscape values, and the multiple consequences of human activities in forests (Ovington 1974). Moreover, important as economics should be in making decisions, the way of life of individuals, families, and tribes, whose heritage is rooted in the forests and related lands, must be respected. It is only by making full use of the inherent skills, characteristics, beliefs, and prejudices of the local people that the general productivity of the land can be improved (Beresford-Pierse 1962).

Our concern here is with forest production, so a logical starting point is to identify those areas that are appropriate for such production. The importance of this step has often been overlooked; however, it is not a simple process. The selection of land must start with a review of the objectives it is to serve. A list of the major purposes of forests that might guide the selection has been adapted from Poore (1976b): (1) support of indigenous peoples, (2) advancement of scientific study, (3) preservation of germplasm, (4) soil and water conservation, (5) public enlightenment, (6) public recreation, (7) biological controls, and 8) production of commodities such as wood.

All tropical forests serve more than one of these purposes. However, most areas are not qualified to serve several equally well. The different purposes are not fully compatible, so providing certain forest benefits limits opportunities for providing others in the same area. Initial uncertainties usually concern how much land is needed for each purpose and how many purposes can be served concurrently on the same area. No one fixed policy can guide all these decisions. Because the process should focus on long-term objectives, it is wise to avoid, minimize, or postpone irreversible decisions that may foreclose options that later might prove superior. Constraints later found to be unnecessary or excessive could easily be liberalized, and any temporary loss of use should be a minor cost.

The dedication of land to forests should be as liberal as is practical for all foreseeable benefits. Throughout the Tropics, too little is known as to what kinds of forests best serve each purpose and how much forest area will eventually be needed for each. Meanwhile, the more land conserved, the more surely future requirements can be met. Ideally, there should be a margin of safety to compensate for possible misjudgments. Compatible multiple uses should be projected for each area.

Land use can be planned rationally by integrated resource analysis (Norton and Walker 1982). A region may be divided into land units, each internally homogeneous as to climate, soil group, slope, vegetation or habitat type, or accessibility. Each may then be assessed as to its capability to provide foreseeably needed benefits. Land capabilities may be represented in a series of maps, with suitability of each land unit for each kind of land use superimposed. When overlaid, these maps present a composite image showing where compatible uses can be integrated and where incompatible uses least impinge on each other. Currently this process is being revolutionized by geographical information systems that sort and overlay different land characteristics electronically.

Application of sound land-use principles to an undeveloped area is illustrated in guidelines recommended for the Amazon (Dubois 1979): (1) until the ecosystems are better known, maintain the largest possible area under protection in unmodified condition, (2) concentrate efforts on consolidation of areas already colonized, (3) limit new settlements to areas of greatest fertility, (4) use production systems that simulate nature, and (5) within settlement areas, determine the suitability of parts of the area for forests.

Forest-Dependent Cultures. The forest resources that must be accommodated first are those most vulnerable to irreversible deterioration from misuse. Indigenous cultures that are forest dependent and individually unique (and therefore vulnerable) are to be found throughout much of tropical America. Areas where tribal customs are integral with the forest, relying heavily on traditional use of areas, soil and plant and animal resources, seasonal migration, and transportation routes, should be recognized as critical to the preservation of such cultures. Those peoples generally are rich reservoirs of information about food plants, medicines, and sustainable life-support strategies as well as social concepts that should be preserved and might prove useful elsewhere. Interaction between forest tribes and the outside world almost invariably erodes delicate balances that traditionally have been worked out between the tribes and their natural environment (Poore 1976b). Therefore, outside uses of such areas, including even recreational and scientific visitations, may have to be rigidly controlled if such cultures are to survive.

Scientific Study. The second most fragile forest resource, organic diversity, outwardly may appear of little value. Benefits from the study of ecosystem diversity and dynamics are only beginning to appear and are proving far reaching. The most fundamental information they yield concerns the interactions within living systems as a whole and between their individual components and the environment-coevolutionary development, interdependence, and symbioses that have guided and could continue to guide human society in its quest for more durable and harmonious ways to live in tropical environments.

Manifestations of evolutionary progress that may be vital to ecosystem welfare can best be discerned in forests where codevelopment of organisms has progressed with minimal disturbance by human intervention. In such environments, because of long relative stability, ecological cause-and-effect relationships are best developed and in evidence. Thus, self-sustaining areas of least-disturbed forests of each major land unit (climatic and edaphic) ideally should be preserved unmodified for nondestructive scientific study. Such areas must remain free of human disturbance throughout an indefinite sequence of studies. They must be large enough to be self-contained and ideally protected by surrounding buffer zones to preserve rare species and migrant animals. For such complex ecosystems as tropical moist forests, self-containment may require either larger reserved areas than might be anticipated (Terborgh 1976) or continuous adjacent forests. Unmodified forest areas also serve as benchmarks for monitoring long-term global changes. In some countries and regions, it is clearly too late to establish ideal reserves of this magnitude, even if public opinion could be promoted to support them. Under such conditions, the reservation of representative climatic and soil areas, even with drastically modified forests or none at all, can nevertheless be in the public interest because, given time, these should gradually revert to forest ecosystems with many of the characteristics of those formerly undisturbed.

Preservation of Biodiversity. A third benefit of native forests is the variety of genotypes of useful or potentially useful species they contain. Many plants and animals critical to the well-being of natural ecosystems—plants that produce food, medicines, and other useful extracts and animals that are esthetically attractive or used as a food source—are distributed sparsely through large expanses of tropical forests and their disappearance must be prevented. Difficulties here are in knowing *a priori* which species will be of greatest future importance, the degree to which they are endangered or significantly different in genotypes, and where in the forest their genotypes occur. For most of the region, neither this knowledge nor the methods to ensure the preservation of all genotypes is at hand; therefore, if rare but possibly useful species are to be preserved, their location and evaluation are urgent. Evaluation may, in fact, be never ending, because new potential values of natural materials continue to be discovered. The preservation of rare species may be partially effected by judiciously selecting forest areas to be reserved, but because this natural condition may be only fortuitous and thus uncertain in the future, early determination of the habitat requirements of critical species is essential to enlightened forest management everywhere. Properly integrated, forest areas allocated for nondestructive, scientific study might be compatible with those used by forest-dependent cultures and those dedicated to preservation of biodiversity.

Soil and Water Conservation. A fourth forest benefit, soil and water conservation, has been widely documented. The significance of forests to erosion and infiltration is illustrated by data from three storms in Cuba on slopes of about 20 percent (table 2–5) (Herrero and others 1975). Particularly impressive is the sharp contrast in erosion among the forest, grassland, and cultivated areas. Although infiltration was about the same in ungrazed grassland and forest, it was lower in cultivated areas.

The superiority of forests in holding soil and infiltrating rainwater is greatest on steep slopes, on loose soils, and under high rainfall intensity. The benefits of forest cover vary also with the magnitude of downstream economic impacts of erosion and floods. Forests for soil and water conservation are thus of high value in rainy areas, but they may also be crucial to soil stability in dry climates where showers, although infrequent, may be intense. Particularly critical are those watersheds serving areas of actually or potentially irrigated floodplain agriculture, usable lowland aquifers, and urban and industrial water sources. Forests for soil and water conservation may also be used for other purposes if their basic protective capacities are not seriously impaired.

Table 2–5.—Vegetation influences on erosion and infiltration in tropical forests in Cuba

Vegetation	Rainfall intensity (mm/min)	Rate of erosion (kg/ha)	Rate of infiltration (mm/min)
40-year broadleaf forest	3.3–3.5	10.4	3.4–3.5
40-year pine forest	2.0–2.3	2.2	2.0–2.3
Ungrazed grassland	3.3–3.5	7.3–115.6	3.3–3.5
Cultivated cassava, 3 months old	2.1–2.3	1,591–4,874	1.7

Source: Herrera and others 1975.

The importance of forests to the borders of river courses is especially evident along the Amazon, where widespread deforestation in some areas has so deteriorated the water that former aquatic organisms have disappeared and disease vectors have spread (Sioli and others 1969). Good silviculture, however, can prevent such consequences. Forest areas allocated for soil and water conservation need not be unsuitable for forest-dependent cultures, preservation of biodiversity, and nondestructive scientific study.

Public Enlightenment. The full benefits of forests will never be realized without the understanding and support of the general public, including even people remote from the forests. Public understanding cannot be expected without some degree of firsthand knowledge of forests and their benefits. Special provisions are needed to influence people to visit forests that demonstrate these benefits. Appropriate forests need to be identified, maintained, and developed to serve this purpose. Special attention is required to attract youth, particularly students. Ideally, forest visitation, instruction, and investigation should be incorporated into educational curricula. What may be needed is a network of educational forest areas representative of the range of forest benefits and sufficiently close to population centers to facilitate public visitation, such as exists in Puerto Rico (fig. 2–17). These areas should demonstrate the benefits of enlightened management. Visitors should learn about such forests on foot, so the area need not be large. Forest areas allocated for public enlightenment should be so managed as to be fully compatible with preservation of biodiversity and soil and water conservation.

Public Recreation. Camping in, exploring, and visiting forest areas of scenic beauty and favorable climate are all recognized therapies for increasingly frenetic urban life. The term "vacation" means literally to vacate, or get away from, the routine. For that purpose, extensive forests are desirable to provide adventure as well as less strenuous recreation, but they need not all be forests otherwise unused. They must be reasonably accessible to population centers, and a small part of the area, preferably on the periphery, may provide basic facilities for accommodating visitors. One product of forest recreation will be greater public appreciation of forest benefits and forestry needs. Forest areas allocated for public recreation, properly developed, should be compatible with soil and water conservation and public enlightenment (fig. 2–18).

Commodity Production. The need for tropical forests to supply wood and other products is shown in recent wood consumption statistics for the region (table 2–6). An increase in use of more than 20 percent in wood and 13 percent in pulp and paper products took place from 1982 to 1992 (Anon. 1993b) and is likely to continue. Although the FAO figures are imprecise, they suggest a slight decline in wood use per capita from 1.00 to 0.96 m^3 and in pulp and paper products from 45 to 42 kg. Forest land selected for production must be capable of producing repeated crops of trees of good form and growth where topography and access facilitate harvesting and marketing. The forest area required to meet increasing demand may be only a small portion of the total forest area but must increase over time or be made increasingly productive, or both. At the very least, forest land dedicated to wood production should be adequate to meet projected future needs based on the productivity that can be expected from forseeably intensive management.

In selecting land for wood production, practical limits of productivity must be recognized. For example, in Bolivia, the best mahogany forests are in the lowlands, but these areas are also clearly suitable for agriculture and

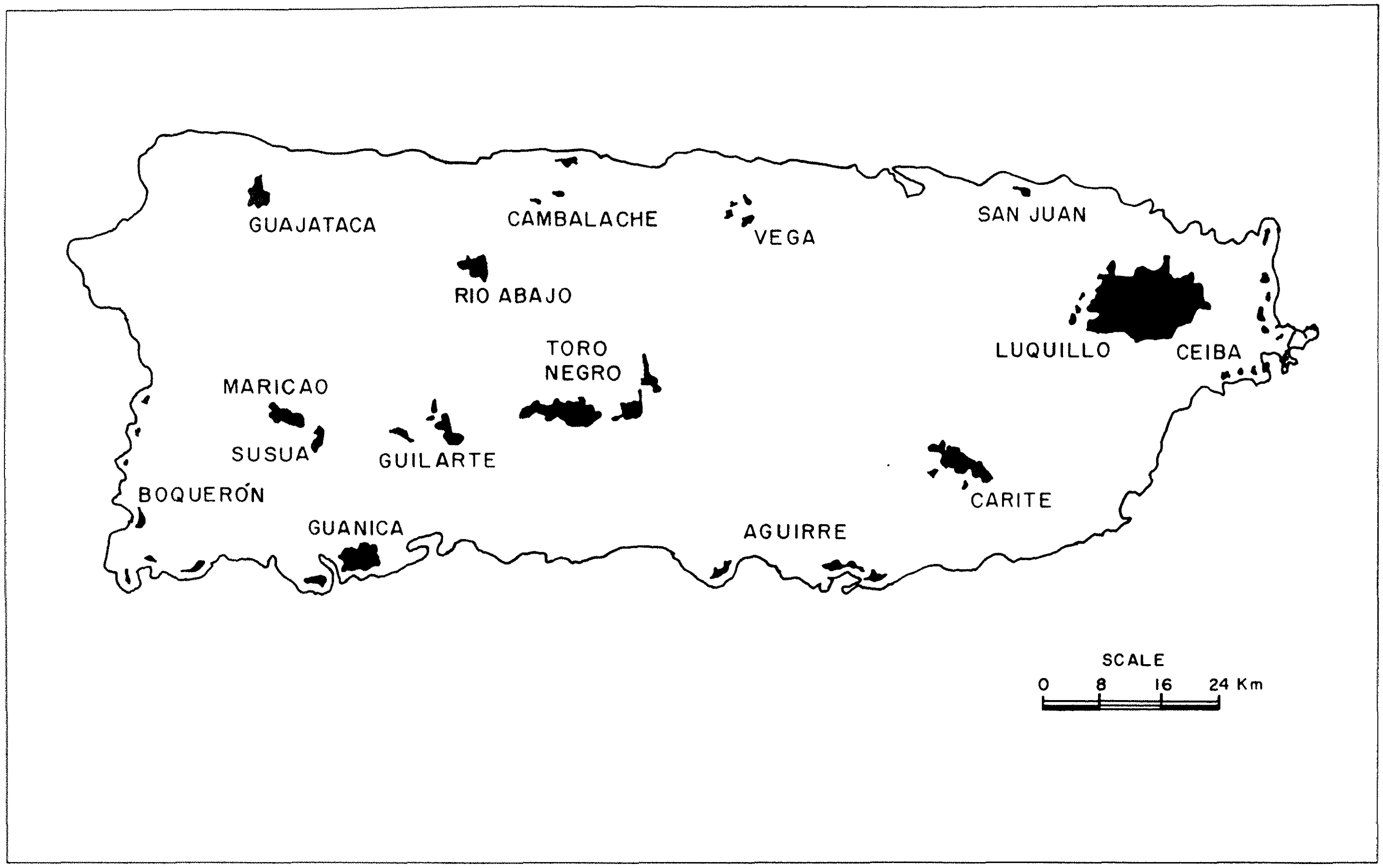

Figure 2–17.—*The public forest reserve system of Puerto Rico, representing diverse climates, soils, and ecosystems.*

possibly best used for that purpose (Scott 1961). At the other extreme, Brazil's dry forest land, the so-called "campos cerrados," considered by Beard (1953) to be a result of extremes of flooding and dryness on impoverished senile Latosols, shows evidence of water 2 to 3 m below the surface (Denevan 1965, Ferri 1961, Rawitscher 1950, Young 1976). Barring fire, it may thus be possible to establish forests there. Their potential timber productivity would of course need study.

Intermediate examples are the various soil conditions of the Amazon. Dubois (1971) recommended that the mangroves be used to produce tannin; the tidal varzea be used for timber, palm oil, rubber, and cocoa; the seasonal varzea for timber and forage; and the shallow soil *facies* of *igapó* (long-term flooded forest) for timber. On terra firme, Dubois proposed a combination of timber, perennial food crops, pasture, and shifting cultivation. Crops such as Brazil nuts would be grown in addition.

The production of forest commodities, because it calls for modifying the forest, may conflict with the preservation of biodiversity and public recreation. However, properly integrated, it should be compatible with forest-dependent cultures and soil and water conservation.

Integration of Forest Uses. Assessing the optimum potential benefits of tropical forests may appear futile in view of the social difficulties inherent in halting further uncontrolled felling of state-owned forests for shifting cultivation and other forms of agriculture. Only rational goals should guide land-use planning. So planning must expose the nature and magnitude of any sacrifices of forest area that may have to be made to accommodate important (or inevitable) nonforest land uses, as well as those inherent in shifts among forest uses.

Because no land area can produce all the desired benefits, the role of individual forests must be determined by

Figure 2–18.—*Enjoyable forest recreation can be provided with simple facilities at natural beauty spots such as in this forest in Puerto Rico.*

Table 2–6.—Indicative wood consumption in tropical America, 1992

Region	Wood product consumption	
	Wood products (million m^3)	Pulp, paper, and paperboard (million tonnes)
Mexico	23.1	4.3
Central America	31.2	.6
Caribbean	11.9	.6
Tropical South America	315.2	10.8
Total	**381.4**	**16.3**

Source: Anon. 1993a.

Note: Consumption is derived by adding imports to production and subtracting exports.

compromises. Each possible use yields different benefits accruing over different periods, and many forest benefits are difficult to quantify economically. One axiom is to assign a high value to those that are unique or require forests and, that once modified, would never again serve their original purpose. These areas in most need of total protection from destructive outside influences (tribal lands, virgin ecosystems, and areas with rare species) may not be those that promise highest immediate economic returns.

The incompatibility of different forest uses suggests that no one benefit would be maximized, even on those areas where it seems most appropriate. For example, forest production may have to be less than maximized to preserve soil, water quality, and animal habitats.

Production Policies

The primary productivity, biodiversity, and long-term stability of natural ecosystems may be unexpectedly compromised by human intervention. How this can be accommodated without permanent loss of these values is a major ecological challenge (Farnworth and Golley 1973). The complexity of this issue must not be lost on the forestry profession. Meyer and others (1961) concluded many years ago that in few other fields of resource management are goals as difficult to achieve, or the problems as complex, or efforts as far reaching as in the management of forests. The fundamental reason for human intervention in forest production is that nature requires too long a time to produce certain values useful to humans.

Laurie (1962) referred to the great homage that has been paid to *biocenosis,* the biological balance and harmony that exist in natural forests but that are not ideal for producing useful forest products. Proper silviculture is seen as a compromise between a close following of nature and adherence to short-term economic considerations (Smith 1962). A managed forest composed mainly of useful tree species may be widely different from the climax association; yet, it may be more vigorous, more productive, and safer from injury (Smith 1962).

Treatments to immediately increase yields, such as regulating stand composition, stand structure, or density, reduce the degree to which forests utilize sites (Spurr 1961). But treatments that affect site productivity or a stand's genetic potential are effective only over long periods.

Balanced production of both economic and cultural forest values calls for finesse in underdeveloped areas because of the perceived desperate need for early financial returns. Two opposite approaches to integrating these goals have been proposed (Dawkins 1964b). One is to manage commercial forests for their other values also. The other approach is to develop wood production in forests that must be preserved primarily for noncommodity values.

Policies must reflect the broad scope of forest production needed in the Tropics. One policy concerns the relative emphasis placed on forest products and services. It may seem desirable to produce as much of the local timber requirement as possible to minimize importation costs. However, there is generally also a need to preserve representative ecosystems, natural wildlife habitats, or scenic forests for recreation and tourism, goals not fully compatible with maximum timber production. The solution, eventual if not immediate, does not lie in geographic separation of forest uses but in their integration. The proper balance means some degree of compromise, depending upon the extent of forest land available. No general rule applies; rather, each country's needs must be considered independently.

A second policy concerns the degree to which forest production is to serve domestic or foreign markets. The apparent advantages of supplying the local market may be partly offset by opportunities to export fine timbers offering greater net return. On the other hand, for national security reasons, heavy dependence on trade for both sources and markets may be precarious; therefore, the optimum solution here may be a political decision in which economic returns are but one factor.

A third policy concerns the relative emphasis on public or private forest production. In most countries of the region, the forests have largely passed from public to private ownership; the government serves mainly as a stimulus to private production. On land marginal for farming, the direct returns from wood crops and related employment, once technology has been developed, may also prove financially attractive. But the public has a stake in other forest values, whether or not visibly economic, such as soil rehabilitation and biodiversity. Any remaining publicly owned forest area, however small, may be invaluable as a reserve for social ends that do not interest private landowners and for demonstrations of diversified forest management for these same landowners.

A fourth policy concerns the degree to which multiple uses can (or must) be made of tropical forests. It is impossible to manage a forest for any one of its values without contributing to or detracting from some others. Yet, there may be a big advantage of managing for integrated uses over managing for one economic goal even at some financial cost. The former approach is most attractive for public forest owners; the latter is appropriate for private forests.

A fifth policy concerns trends in yields. A basic tenet of forest management is stability of yields. If current yields are below their potential, it may be possible to increase them to help provide future local timber requirements or nationally important exports. However, any future production goals should not exceed sustainable levels. Harvesting beyond a sustainable rate is justifiable only in time of emergency or some imminent catastrophe that endangers the crop. Normally, removals during the first cycle, even when a large overburden of overmature trees is harvested, should not exceed the expected sustainable yield.

The arguments for setting a sustainable yield as a maximum are legion. Present trends in the rate of product removals from tropical forests show no signs of decline. Failure to ensure prospective yields now can cause far greater future shortages than any sacrifice in present consumption. Sustained yield has been criticized as vague, but it is not. What may be vague is available information to predict yield levels. Maximizing the present worth of all future net forest benefits may appear a sound basis for predicting sustainable yields, but this requires fully assessing intangible forest values and the social and economic impacts of even-flow, variable, or declining yields (Pant 1977). These values are so uncertain that a yield goal may have to be set arbitrarily at some point thought optimum. However imprecisely derived, the concept of sustained yield remains fundamental to forest management. If removals are increased, the sustainability of the increased level must be ensured.

The concept of sustained yields is nevertheless repeatedly challenged as a goal where secondary forests are not equal in quality to primary forests. Although secondary forests may yield the same quantity of products as did the primary forest, they may not yield the same quality. Moreover, with most other human aspirations in the Tropics so short term, sacrificing present consumption of tree crops to sustain distant future yields has been challenged as blatantly opposed to the realities of the developing world (Leslie 1977). However, such "realities" themselves seem out of synchrony with the future. Thus, despite a continuing decline in forest area, sustained yields must be a goal of forest production. Sustained yields are indeed the very foundation of forestry (Gentle 1987).

The principle of sustainability must not dogmatically cling to the size and composition of the original timber crops. Management must seek high yields of those products most needed in the future, not the present, including smaller trees and species not now used. Both of these changes are legitimate components of sustained future productivity.

Forest Protection. Forest production begins with the protection of existing forests. Protection does not necessarily mean preventing use of or modifying the forests. Indeed, the word "conservation" has been defined as "wise use" (Leopold 1933). Some forests, as already noted, are on land that might be better used for other purposes. Nevertheless, all forests, by their mere presence, yield some benefits. They may be the best and least expensive custodians of the land. Unless there is clearly a better, sustainable, land-use alternative, rational argument favors protecting and conserving existing forests.

Protecting forests means more than simply preventing their destruction. Most forest values are systemic, the contributions of countless organisms interacting to utilize and store up energy and nutrients that would otherwise be lost. Protection, then, means safeguarding this process even in forests in no immediate threat of removal. Harvesting the best specimens of one or more species of plants or animals can severely affect the remaining ecosystem. Adding solid, liquid, or gaseous wastes from human activities can also place forests under stress. Examples are disposal of raw sewage into swamp forests and the emission of vehicular exhaust into forests along major highways.

The precise level of protection necessary is uncertain because the requirements and resources of forests are incompletely known and probably are assessed only superficially. The diverse utility of plant resources in tropical forests is indicated by the number of species used for different purposes by peoples who have lived for centuries in the forest environment. In northwest Amazonia alone, some 1,600 medicinal and hallucinogenic plants have been found (Schultes and Raffauf 1990). Another 798 medicinal plants are described for the Caribbean region (Liogier 1990).

Other forest products include latexes, gums, fruits, nuts, canes, and honey. These have been extracted chiefly from natural forests and have received only minor attention in forest productivity efforts. Some oleoresins, such as "elemi" from *Amyris, Canarium,* and *Proteum,* are used in the manufacture of varnish and paints, plastics, and printing ink (Tongacan 1972). Gutta-percha latex from *Palaquium* and balata gum from *Manilkara* are nonelastic, decay-resistant rubbers widely used for insulating subterranean or submarine cables (Tongacan 1971). Chicle, also from *Manilkara,* an ingredient of chewing gum, has been legally protected in the forests of southern Mexico. Tannins, formerly from mangroves, have been produced intensively in plantations of *Acacia* and *Albizia* (Tongacan 1973). Rattan comes from several species of *Calamus,* mostly vinelike members of native forests (fig. 2–19). They have been propagated in India on a 15-year rotation (Ordinario 1973). The harvest of Brazil nuts is of sufficient economic importance in Brazil to merit a national law prohibiting the felling of mature trees. The value of honey and beeswax from native forests in Tanzania has been sufficient to justify preservation of large woodland areas (Tesha 1968).

A partial list of products other than wood from the forest plants of India appears in table 2–7 (Krishna Murthy 1967, 1974).

Human society will certainly want more (rather than less) forest product diversity in the future. Preservation of that diversity at its source calls for perpetual protection of representative forests as storehouses of undiscovered knowledge.

Protection involves patrolling to monitor and prevent misuse of forests. A far larger but more rewarding task is to mold public opinion to support rather than resist forest protection. This calls for a continuous broad-scale effort,

Figure 2–19.—*Several varieties of rattan come from lianas in the tropical forests of the Asia-Pacific region.*

Table 2–7.—Nontimber products derived from forests in India

Product	No. of forest species[a]	Product	No. of forest species[a]
Medicinal	1,800	Cellulose	44
Human food	280	Cover crops	26
Dyes	112	Fish poisons, pesticides	24
Fibers	100	Beverages	16
Tannin	78	Beads	13
Fatty oils	75	Green manure	11
Fodder	75	Saponins	10
Gums and resins	75	Latex	3
Baskets and canes	60	Other	>100
Essential oils	44		

Source: Krishna Murthy 1967, 1974.

[a]Number of different species used for each purpose.

using all available media to convince urban people especially that forests are beneficial not only for the production of commodities but for many other purposes.

The same degree of protection afforded existing forests may be justified on unforested forest land. Adequately protected, most such land can be expected to return to forests, some with no investment other than protection. And these new forests can control erosion, restore rainwater infiltration, store nutrients, and develop systemic benefits. Protection is needed primarily against fire and grazing and, as the trees reach usable size, against excessive removals for fuel or forage.

The Convention on International Trade in Endangered Species has classified a number of plant and animal species to be restrained from international trade except where sustainability is not jeopardized. Currently listed tree species from tropical America are: *Abies guatemalensis, Balmea stormiae, Caryocar costaricense, Dalbergia nigra, Guaiacum officinale, G. sanctum, Oreomunnea pterocarpa, Platymiscium pleiostachyum, Podocarpus parlatorei, Swietenia humilis,* and *S. mahagoni.*

Selection of Products. The products or benefits desired from forests are critical to their management. Forest production encompasses the whole realm of benefits, including such intangibles as public appreciation of recreational and educational opportunities provided by forests. Enlightened forest production must take these intangibles into account, for ultimately it depends upon, affects, and is affected by them. Forests managed as a source of ecological information may need only protection and access for research. Forests managed for rare species may be given intensive protection and made accessible for studies that could help preserve the species. Forests used for public education or recreation require safe public access, facilities to provide needed services, inventories or monitoring to quantify what is being demonstrated, and trained personnel to ensure proper and effective use of the areas.

The production of wildlife may not become a sole objective of forest management in many parts of tropical America. However, management generally should ensure the welfare of the ecosystem's wildlife. All forms of animal life perform significant, sometimes critical, roles in the forest ecosystem, still far from fully understood, (e.g., in pollination, seed dispersal, decomposition, and maintaining soil quality). Forests harbor many species of animals that would disappear unless necessary forest conditions persist.

All forests are significant to soil and water conservation. Forests can give maximum protection to the soil and capture a maximum amount of rainwater, from which they can extract a maximum of energy before they release the water that passes through them (Hoover 1962). These attributes dictate a policy of leaving some natural forests without unnecessary disturbance. In forests where commodities are to be produced, the importance of watershed protection should generally be fundamental to cultural and harvesting practices.

The most common direct use of the forest is for wood and its derivatives. In the Tropics, consumption of wood for fuel ranks first, followed by the rapidly growing use of fiber products such as paperboard and paper. Other high-use industrial wood products include utility poles and piling, construction lumber, plywood and veneers, furniture and cabinet woods, and specialty woods for novelties such as turnery items and matches.

One woody material not yet fully utilized in tropical America is bamboo. In the Philippines, bamboo has been used for house construction, carts, trellises, outriggers, scaffolding, agricultural implements, hats, baskets, rope, fish traps, matting, furniture, and paper (Fernandez 1951). Bamboo has also been used for paper in Cambodia, India, Indonesia, Pakistan, and Thailand (Doat 1967).

Forests provide fuelwood for most of the world's population. In 1992, some 1.51 billion m^3 of wood was removed from the world's forests for fuel including charcoal (Anon. 1993b). The demand in the Eastern Hemisphere is so great that plantations of *Albizia lebbek, Bauhinia variegata, Dalbergia sissoo,* and *Prosopis juliflora* have been maintained at great public expense to provide fuelwood (Misra 1960, Singh 1951). There is a long history of forest fuel production in tropical Asia, where only about 0.03 ha of forest per capita remains (Anon. 1993b).

Fuelwood is also heavily used in tropical America, particularly where the population is concentrated in dry climates. Moreover, some of the region's most extensive and best-managed plantations are those of *Eucalyptus* grown for Brazil's steel industry. Because of the rising price of imported petroleum, the potential fuel yields of Brazil's *Eucalyptus* plantations were calculated (Anon. 1979c). On a 5-year rotation, an annual yield of 12,500 t of wood per 1,000 ha is expected. This amount of wood, in turn, could yield 2.3 to 2.5 million L of ethanol, 1 to 1.8 thousand t of high-quality metallurgical coke, 2,000 t of animal feed, and 1.4 million kg of carbon dioxide.

From this calculation, it was concluded that 2 million ha of *Eucalyptus* planted in 1979 would provide enough ethanol to replace 19 percent of the country's projected petroleum consumption in 1984 (Anon. 1979e). *Eucalyptus* plantations in South Africa have been found to convert about 0.5 percent of solar energy into useful fuel (Grut 1975).

Energy requirements in the region point to increasing demands for fuelwood production. The world's total supply of energy was estimated in 1976 at 27.7 billion joules (Burley 1980c). Wood then supplied only about 1 percent of this energy (Earl 1975) but 66 percent of the fuel consumed in Africa (Burley 1980c), 29 percent in Asia, and 20 percent in tropical America.

Fuelwood supplies, limited naturally in dry forest areas, have become locally critical in almost every tropical American country. Many areas of the region are fuelwood deficient, some of them suffering acute scarcity.

Where other, more efficient, fuels are available, wood and charcoal are less frequently used. Per unit of weight, air-dry wood has less than half the caloric value of fuel oil and only two-thirds that of coal. The corresponding percentages for charcoal are 72 and 103 percent (Earl 1975). Nevertheless, in the Tropics, wood tends to be the most economical fuel because its cost is chiefly human labor. Thus, fuelwood's place in future forest production in the Tropics seems assured. Alternative fuels are rising in price more rapidly than fuelwood and generally must be imported.

Wood-energy goals involve wood quality as well as quantity. Wood's caloric value increases with its density (a correlation of +0.99 for each calorie per cubic centimeter) (Doat 1977). Extreme values found with Suriname woods were 1,940 cal/cm^3 for *Cecropia surinamensis,* which has a specific gravity of 0.42, and 5,000 cal/cm^3 for *Tabebuia serratifolia,* which has a specific gravity of 1.04 (Doat 1977).

Wood moisture content is critical to the net heat available from wood, because driving off moisture consumes heat. The net heat yield of wood with 60 percent moisture content is about a third less than that of wood with 20 percent moisture content (Murphy and others 1981). Therefore, use of green wood might nullify possible benefits from silvicultural stimulation of forest growth (table 2–8; Anon. 1980g).

Moist tropical forests may contain the heat energy equivalent of more than 50,000 L of fuel oil on 1 ha (Catinot 1974). *Eucalyptus* plantations in Brazil yielding 30 to 40 m^3/ha/yr produce an energy equivalent of 5,000 to 5,500 L of fuel oil per hectare per year.

Table 2–8.—Effects of moisture content on the heat value of wood

Moisture content[a] (%)	Heat value (kcal/m³)	Loss due to moisture (%)
0	4,670	0
20	3,780	19
40	3,160	32
60	2,710	42
80	2,380	49
100	2,070	56

Source: Anon. 1980g.
[a]Based on dry weight.

Earl (1975) made a good case for setting national production goals for fuelwood plantations in the Tropics. He points out that where low income and meager fuel supplies prevail, financial returns from fuelwood plantations may be submarginal, but the social benefits are often very high. Because the social cost of underemployed labor may be much lower than the wages the forest authority must pay, wages are in effect a subsidy to the labor force. Producing fuelwood is labor intensive, and the wages paid to the rural sector have a ripple effect locally.

Wood's value as a fuel substitute is graphically illustrated in densely populated India, where cow dung is burned for fuel. Cow dung has a fertility value more than double its value as a direct source of heat, but it is nevertheless burned (knowingly to the detriment of the soil) because of a lack of fuelwood (Sagreiya and Venkataramany 1962). It was estimated by Foot (1968a) that replacing cow dung with wood fuel in India would require an increase in wood production of 3.4 million m^3 annually.

Sources for fuelwood depend partly on the presence of other forest industries. Where sawtimber and pulpwood are both in demand, chips for heating may sell at only 10 percent as much as an equal volume of sawtimber or 35 percent as much as pulpwood. Thus, fuel can compete for only the wood fraction not acceptable for these other uses (Murphy and others 1981). However, the industries serving these other wood outlets create low-cost residues both in the forest and from processing that may equal 50 to 70 percent of the volume of the trees felled. Therefore, statements about the economic feasibility of producing energy from wood are seldom widely applicable. Case-by-case analysis is necessary. Price changes for fossil fuels call for periodic reevaluation of the potential energy production from forests.

Next to fuelwood, the most widely used solid-wood product in the Tropics may be fenceposts. Where dairy and beef cattle are important, establishing fencepost production goals is wise. Where there is a good post market, plantations may be closely spaced to allow a large volume of posts from thinnings. Receipts from the sale of posts may assist in amortizing plantation investments. There is some advantage and need for live fenceposts, tree species that sprout readily or can become permanent supports for fencewire. But such trees generally serve only in certain fences, so the market for cut posts will persist.

The presence in tropical forests of cabinet woods of a quality rare in the Temperate Zone has led to large-scale exportation of such timbers. Because high-quality cabinet wood comes from wide boards from large-diameter logs or from veneer peeled from large logs, past silvicultural treatments have been directed toward the production of large trees. Management has aimed at spreading the harvest of primary forests over a period long enough to permit maturation of residual adolescents or a new tree crop. Growth data revealed that rotations up to 80 years would be required to produce the trees 90 to 120 cm in d.b.h. that the importers have come to expect. The famous teak plantations at Nilambur, India, have been managed on an 80-year rotation. Wyatt-Smith (1959) predicted a 70-year rotation for his Malayan uniform system. The management plan for the natural forests of Uganda also used 70 years (Dawkins 1958g).

The fact that there were only a few large trees in mixed forests that were marketable led to the question of what to do with the 90 to 95 percent of the standing volume for which there was then no market. With improved access, rising population, and more information about little-used woods, markets are appearing for many more tropical timbers. In some places, local markets exist for fiber from 90 percent of the tree species of the forests (Frisk 1979). The properties and potential uses of hundreds of tropical American woods have been studied (Berni and others 1979, Chudnoff 1984, Mainieri and others 1983). This knowledge has opened up opportunities to utilize more of the natural stands, accept more options as satisfactory regeneration, shorten rotations, and extract intermediate harvests. Particularly significant to this change has been the growth of the market for cellulose. The wood of rapidly growing genera such as *Eucalyptus* and *Pinus* is suitable for this market.

In considering short rotations, Baskerville (1966) warned that foresters must not assume that loggers will harvest the maximum volume the plantation can produce. He pointed out that all known wood manufacturing processes are linear; small trees cannot be handled as cheaply per unit of volume as large ones. Profitability is thus directly sensitive to tree size.

A special objective of tropical forest production has been to satisfy wood requirements of rural villages, a practice that began in India in 1873 (Kapoor 1961) to eliminate the use of dung for fuel. Areas have been selected for village forests where fuelwood shortages are acute and prospects for cooperation are good. Badly eroded areas and existing forests are protected from grazing, and fire and gaps are planted. Other idle land, such as roadsides, canal banks, and field boundaries, has also been put to use (Kapoor 1961). Even shade trees and garden plantings are included. Village forests usually have been 20 ha or more in area. Tree species planted include *Prosopis* spp., *Casuarina* spp., and *Dalbergia sissoo* (Kaul and Maun 1977). The success of such ventures requires winning the cooperation and participation of the local leaders (Phillips 1961).

Predictable trends in the market for forest products and the social need for forest benefits should determine national goals for the size and types of forests required. Lamb (1968c) saw a need for production goals directly related to prospective demands, including exports. He points out that tropical high forests are a source of valuable timbers that can be produced nowhere else in the world. Supplies are seriously depleted. Population pressures make it desirable in many countries to produce useful timber from every available and suitable hectare. Consumption of tropical wood is trending away from species-sensitive products toward mass processing. Nevertheless, the outstanding beauty and decorative value of tropical woods may well continue the demand for specialized tropical wood products (Erfurth 1976).

Production Goals. Forest production, as a long-term commitment, requires defining long-term goals. These may be diverse and widely separated in time. Goal setting involves some factors only indirectly related to the forests. Social, economic, and silvicultural considerations must be integrated. Until goals have been defined, no large-scale forest production venture, public or private, can be wisely directed.

The presence or absence of forest cover has in the past determined the fate of traditional societies (Sartorius and Henle 1968). The ills that beset tropical peoples are due less to any "insufficiencies" of nature than to the misdirection of society. The potential exists to ameliorate tropical deforestation and its consequences through changes that society wants. To accomplish this, forest planning must focus on goals that are broad in scope (King 1968b).

As seen by Miller (1975), forestry in 1975 stood at the threshold of an opportunity to participate in major global efforts to achieve sustainable use of living natural resources. Initiatives identified for this purpose included ensuring the protection of species and forest areas, determining conservation strategies, implementing practices that serve the needs of the rural population, and restoring depleted land.

Conservation requires legalized forest protection, but that is not enough. In South America, legally established parks and nature reserves were estimated to include 489,000 km^2, nearly three times the area so reserved in the United States (Mares 1986). Yet, it is common knowledge that much of this area is neither productive nor indeed adequately protected. *Management* is as necessary to the production of forests as is legal protection.

Forest-production goals should be coordinated globally, since the ultimate social and economic self-interest of all nations is inevitably merged with all others. Within each country, forest production must be coordinated within the context of the local economy, considering population, land, food, other resources, and traditions. The interaction of these factors will decide national goals for forest production.

The social as well as economic values of forest production are generally underestimated in national planning. The share of the gross domestic product of a country credited to timber (usually well below 10 percent) is grossly unrealistic (Sartorius and Henle 1968). Timber production and processing are multifaceted enterprises, requiring many employees and affecting related industries. Thus, investments in timber production and processing have a greater influence on the economy than is usually reflected in statistics.

Nor is the potential significance of timber production to the balance of payments of developing nations fully recognized. Developing countries suffer from trade deficits that may be exacerbated by shipping charges attributable to the use of foreign vessels. Moreover, development may be crippled by diverting foreign earnings into imports of forest products that could be produced locally. Imports are recurring expenses, whereas investment in processing of local raw materials, even if greater at the outset, may be a onetime cost. Probably no product offers a greater opportunity for domestic investment leading to a healthier national balance of payments than does locally produced timber.

Traditional comparisons of costs and benefits tend to undervalue forest production because rates for discounting over long periods are unreliable and because indirect forest benefits cannot be expressed in monetary terms. In assessing the value of forest investments, opportunities for employment and earnings must also be credited.

In developing nations, the forest economy must fulfill more extensive functions than elsewhere. Among these is maximum employment of masses of rural people at their skill level. The most desirable industry in developing countries would generate jobs quickly and use local raw materials to make products for local consumption. Employment may be more important than productivity of goods and services. Silviculture and forest regeneration normally require large amounts of manual as well as skilled labor, and they pay off by increasing or improving forest capital, the growing stock.

Production goals are also affected by the amount of the tree that is usable. This may depend upon the minimum diameter that can be utilized and the width of the useful heartwood and less useful sapwood. These considerations also affect selection of species, rotations, and pruning and thinning regimes.

Another source of diversity in forests is genetic. A wide range of genetic potential exists. Genetic manipulation can produce trees with characteristics not found in nature. Genetic modifications may result in trees that can thrive on sites now considered marginal, thus allowing an increase in productive forest area. To conserve these options, different natural genotypes of native tree populations must be preserved.

Solid-wood processing, unlike other raw-material processing, does not require complicated, expensive machinery. Because the raw material for wood processing is bulky and heavy, there is an incentive to locate industries in rural areas near forests where economic development is most needed. For products such as lumber, veneer, and particleboard, small production units that require little capital and managerial ability and take advantage of traditional skills can operate profitably. The raw-material and employment values of forest products are relatively high. For sawmill products, raw material may make up 50 to 75 percent of total production cost. Milling may employ 10 to 15 hours of labor per m^3. Plywood manufacture may employ 10 to 20 hours of labor per t and does not require high-quality woods, fresh water, or large power supplies. Moreover, forest production focused on goals for projects such as these can easily be redirected should products less demanding as to tree size and species come to the forefront in the future.

Employment is so important to developing countries that it may be better to discount competitiveness among alternatives and emphasize productivity as a forestry goal (Sartorius and Henle 1968). Competitive approaches to the opening of local resources and satisfaction of local demands may not overcome employment stagnation, but rather a need for mass employment may transcend all considerations of direct economic returns. The multiplier effect of operations connected with industrial wood processing varies from 4 to 17 (Svanqvist 1976).

Less mechanization may be desirable in the Tropics than in developed countries because mechanization usually depends on imported machinery and specialized training (Sartorius and Henle 1968). Sociological (as well as technical and economic) factors must help decide the most appropriate degree of mechanization.

Timber production and resultant local industrial development, great as their contributions may be, are inadequate social goals for tropical forestry. Forest industries in developing countries must have public support, sound planning, and adequate safeguards, and governmental forestry agencies with broad social goals and regulatory power must be developed. The alternative is haphazard mobilization in uncontrolled directions while weak forestry agencies stand helplessly by.

Silviculture. To date, tropical forests have been managed chiefly for the production of wood rather than for other products or benefits. Silviculture, including the stimulation of productivity of secondary forests and regeneration, is treated in greater detail in later chapters, but its place in forest production is reviewed here.

The culture of tropical forests originated in the practices of early tribes, records of which are not available. It seems certain that the Mayan Empire in Central America, a region of seasonally deciduous forests, must have had its policies regarding the culture of forests just as it had policies for farming. Silviculture as we know it, on the other hand, was first brought from the Temperate Zone to the Tropics in the Eastern Hemisphere in 1855 (Parker 1923).

Silviculture has always been allied with forest ecology. Foresters have helped identify forest trees and forest types and have studied their responses to site and stand conditions, both natural and imposed. If ecology was the approach, silviculture was the application by foresters. All successful foresters, from conservators who direct forestry programs to guards that patrol the forests, may be termed practicing ecologists. Most have made no record of the accumulated wisdom of their personal observations. Outstanding sources of pertinent literature include Foxworthy (1909), Watson (1928), and Wyatt-Smith (1961a) for Malaysia; van Steenis (1958) for Indonesia; Troup (1921) and Champion and Trevor (1938) for India; Aubreville (1948) for west Africa; and Beard (1944b), Holdridge (1947), Schulz (1960), Hueck (1972), de Graff (1986), and Lamprecht (1989) for tropical America. Champion and Trevor's (1938) manual of silviculture is still a unique source of ecological information about the forests of India. Forestry itself has long been termed "applied ecology" in India (Seth 1955). Almost all technical forest production information has consisted of recorded responses of trees to their environment and interpretation of those responses in terms of marketable productivity. An early manual of silviculture for the forest types of the Western Hemisphere (Fors y Reyes 1947) for the Pozos Dulces Forest School in Cuba began with forest ecology as a basis for recommended practices. For each published report, there were undoubtedly many additional conclusions reached by unsung native field personnel intimately familiar with the components and behavior of their forests.

Although forest managers may have been among the original environmentalists (Ghosh 1975), growing public sensitivity to all tampering with the natural environment has brought forest management under closer public scrutiny. Traditional forest management has included differential treatment of species, intervention into irreplaceable primary forests, clear cutting in publicly visible areas, establishment of pure plantations, introduction of exotic tree species, use of fire for hazard reduction, and use of herbicides and pesticides (Ovington 1974). Although all these practices can enhance timber production and may be acceptable under certain circumstances, none of them is publicly accepted everywhere nowadays. Managers must minimize adverse ecological impacts in preliminary planning and discuss proposals with the public in layman's terms. Otherwise, public criticism, rational and/or emotional, can be expected.

Forestry is sometimes incorrectly presented as purely exploitative, its practitioners obsessed with maximizing wood yield while merely paying lip service to safeguarding other forest values. Some appropriate forestry practices in regulating wild forests are indeed a form of conversion. But their merits have not been adequately justified before the public.

The silvicultural aspects of management go further than the application of ecological knowledge. The amount of energy fixed annually by tropical forests may be large, but it is only by applying sound silvicultural principles and practices that wood production can prosper in quantity and quality. Those responsible for developing forest crops from "seed to sawtimber" must be generalists rather than specialists. But they must also freely use the expertise of specialists in getting maximum benefits from the forest (Singh 1960). While managing the current tree crop, they must also explore the potential of increased productivity through genetic improvement.

A final aspect of forest production is direct service to agriculture, including the use of forests and trees for fodder, shelterbelts and windbreaks, and crop shade, or the utilization of swamps. Fodder production in forests has been undertaken mostly in dry areas of the Eastern Hemisphere, often in conjunction with fuel production. Both the foliage and the pods of species such as *Prosopis juliflora* are eaten by cattle (Singh 1951), whereas just the foliage of *Leucaena leucocephala* is eaten. Other fodder species that have been used in India include *Acacia arabica, Azadirachta indica, Bauhinia variegata,* and *Zizyphus jujuba* (Chaturvedi 1948).

As windbreaks, trees protect crops and thus increase harvests. For example, in Ecuador, cornfields shielded by forests reportedly increased the yield 20 percent over that of unprotected fields (Anon. 1955b). Genera used there include *Cupressus* and *Pinus.* In Peru, *Eucalyptus globulus* is commonly used as a windbreak. Species of *Erythrina* and *Inga* are widely used to provide shade in coffee plantations in Costa Rica, El Salvador, Puerto Rico, Suriname, Trinidad, and Venezuela. *Cordia alliodora* is also used in Colombia and Costa Rica. In Uganda, where swamp drainage for mosquito control is desirable but costly, plantings of *Eucalyptus* and *Senna siamea* have proved effective (Dale 1943).

Examples of Forestry Diversity. The possibilities of forest production are as diverse as the forest conditions and human needs of the Tropics. The forests themselves, as has been seen, are diverse, ranging from dense rain forests to dry scrubs and savannas. The poorest natural forests are likely to be most deserving of attention because of their role in land stability and possibly as a sole fuelwood source. Such forests have usually been further diversified by human intervention, leading to an array of successional secondary forests, differing in character, productivity, and utility.

The extent of a nation's forests itself influences production objectives. Extensive forests call for management intensities different from small forests. For example, extensive secondary forests may best be managed on a basis of natural regeneration with low input/output, providing geographically diffuse rural employment. Where native forests are less extensive, plantations may be needed for high yields per unit of forest area (Earl 1975).

The diverse structure of natural forests may also influence production. Stands may be classified as positive, neutral, or negative depending on how the number of various tree sizes relates to the de Liocourt curve (Sammi 1961) (a constant logarithmic increase in tree numbers from the largest to the smallest classes). Positive stands have an excess of small trees of merchantable species regenerating naturally. Negative stands do not; so, for them, not only must methods to ensure regeneration be devised, but goals in terms of products and yields may have to be adjusted accordingly. An example is a forest rich in *Virola* but with few or no small trees of this species. Unless regeneration of this species can be induced silviculturally, different species, possibly less useful, may be favored by merely harvesting mature *Virola.*

Local variation in the capacity of forest sites to produce different tree species, sustain rapid growth, and yield merchantable trees also affects production goals. For teak in tropical America, for example, different sites produce, at age 30, trees ranging in height from 13 to 30 m and having a mean annual growth ranging from 1 to 11 m^3/ha (Keogh 1979). The advantages of the better sites are obvious.

Environmental extremes, such as hurricane frequency or periods of high fire risk, may influence rotation lengths, tree species, stand densities, and silvicultural practices (Gane 1970).

Finally, where increasing employment is a national priority, the type of forest produced can be critical. According to one estimate, the maximum employment from naturally regenerated forests is about 1 employee for 100 to 125 ha (Svanqvist 1976). Short-rotation plantations, in contrast, can employ 1 person per 15 to 20 ha. Mixed food and long-rotation tree crops may employ 1 person per 7 to 18 ha, but with most of the labor attributable to the agricultural crop.

Experience in Malaysia has shown that forestry can attain diverse goals of national significance (Wyatt-Smith and Vincent 1962b). Among these are the safeguarding of water supplies, the prevention of erosion and flooding of agricultural land, and the supply, in perpetuity, of all forms of forest products that can economically be produced within the country and will be required for agricultural, domestic, and industrial purposes.

In South Africa, extreme measures have been necessary because large areas of the country are treeless (Anon. 1966a). Tree species suitable for timber markets have had to be introduced as well as ways of growing them at a profit. And, finally, plantation timber has had to be converted into products that compete with imports.

In Trinidad, an analysis of forest-production potential revealed some impressive possibilities for future employment (Gane 1969). Expanding tropical shelterwood treatment from 160 to 200 ha/yr could double gainful employment from forests and their products in 60 years. Increasing the planting of pine and teak from 280 to 320 ha/yr would result in even greater gains. Employment in teak production and processing would be double that in shelterwood, and employment in pine would surpass shelterwood sevenfold.

In Uganda, analysis of national wood requirements clarified goals for forestry (Dawkins 1958e). Because more wood would be needed in the future and importation was not an economical option, local production was imperative. However, plantations had proved so expensive that, no matter how productive they might become, their establishment was likely to be slow. Accordingly, the extensive natural forests were considered the primary timber source. Forestry objectives were as follows (Dawkins 1958e):

- Two percent of the forest was to be set aside to preserve its natural development
- Amenities, agriculture, and water supplies were to be protected by forests
- Wood production was to conform to protection needs and not be undertaken where preservation of nature was a goal
- Wood production was to be sufficient for the diverse needs of the country's inhabitants
- Emphasis was to be on timber for buildings and furniture, woods that were strong, easy to work, and preferably permeable
- Production efficiency was to be maximized.

The goals of forestry in tropical America must be multidimensional and highly diverse. The important thing to recognize is the imperative need for goals that are (1) firmly established and stable, (2) technologically sound, (3) socially acceptable, and (4) subject to the selection, preparation, execution, and evaluation of forestry projects and activities.