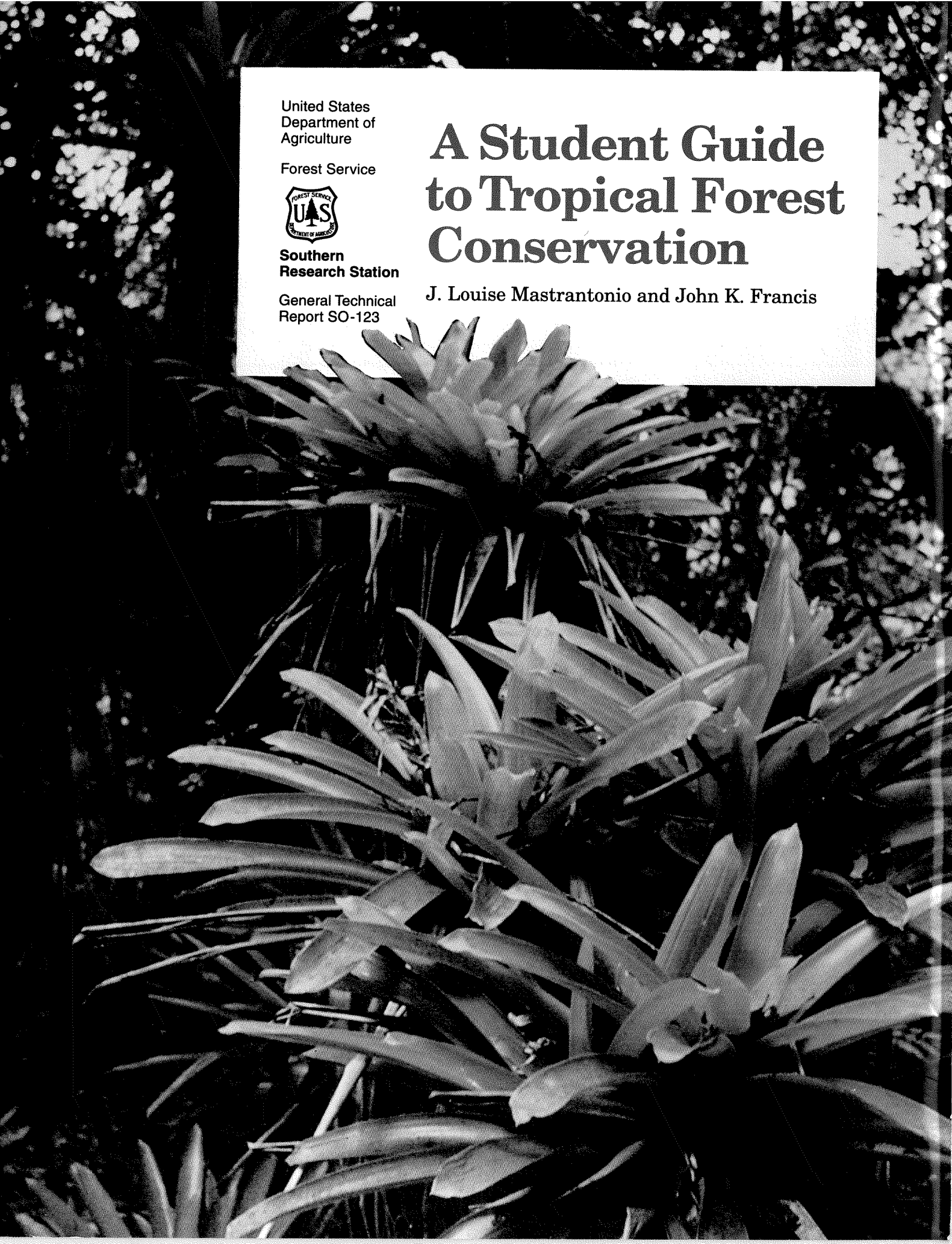

United States
Department of
Agriculture

Forest Service

**Southern
Research Station**

General Technical
Report SO-123

A Student Guide to Tropical Forest Conservation

J. Louise Mastrantonio and John K. Francis

Cover: Bromeliads festoon the trunks and branches of dwarf trees found in the cloud forests of the Luquillo Mountains in Puerto Rico. (photo by John Parrotta)

SUMMARY

The world's tropical forests, which circle the globe, are interestingly diverse. Ranging from the steamy jungles of the rain forests to the dry forests and savannas, they provide habitat for millions of species of plants and animals. Once covering some 15.3 billion acres (6.2 billion ha), these tropical forests have been reduced through cutting and clearing by 210 million acres (85 million ha) between 1985 and 1990. All types of tropical forests are defined and their products and benefits to the environment are presented and discussed. Modern forest practices are shown as a means of halting forest destruction while still providing valuable forest products and protecting and preserving the habitats of many endangered species of plants and wildlife. The Luquillo Experimental Forest is presented as a possible model to exemplify forestry practices and research that could manage and ultimately protect the tropical forests throughout the world.

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A STUDENT GUIDE TO TROPICAL FOREST CONSERVATION

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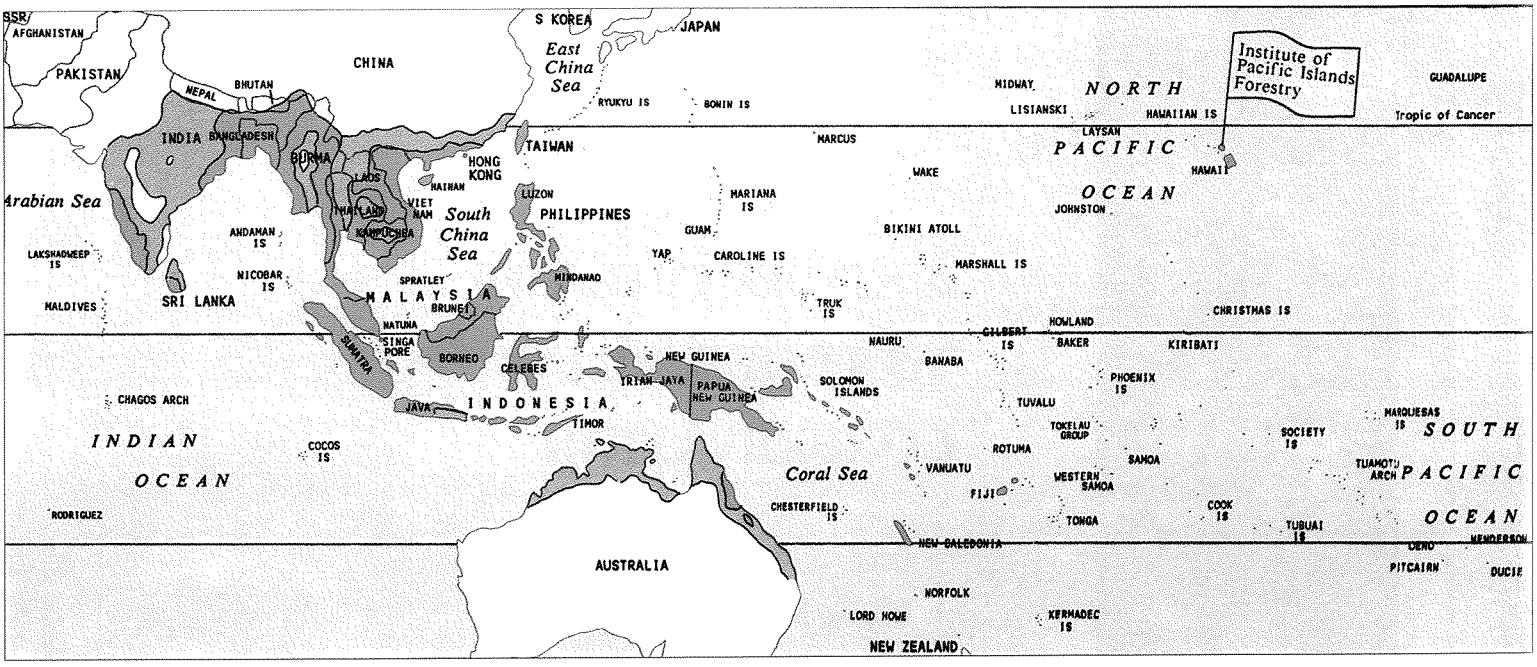
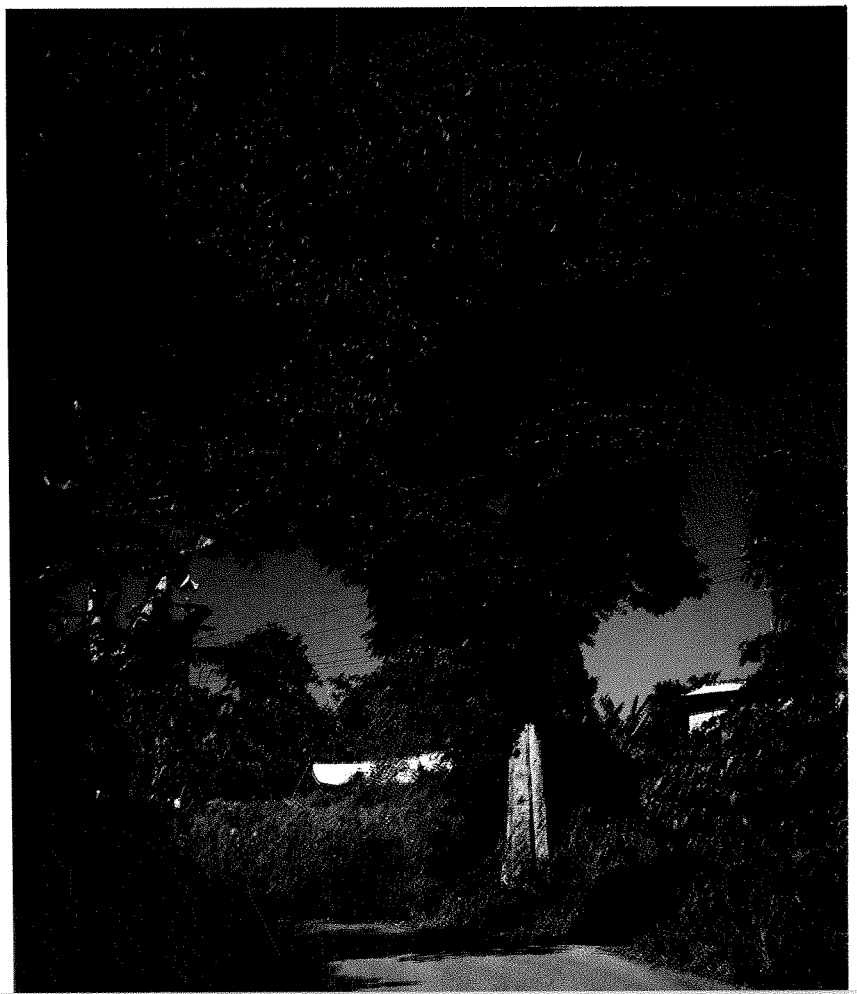
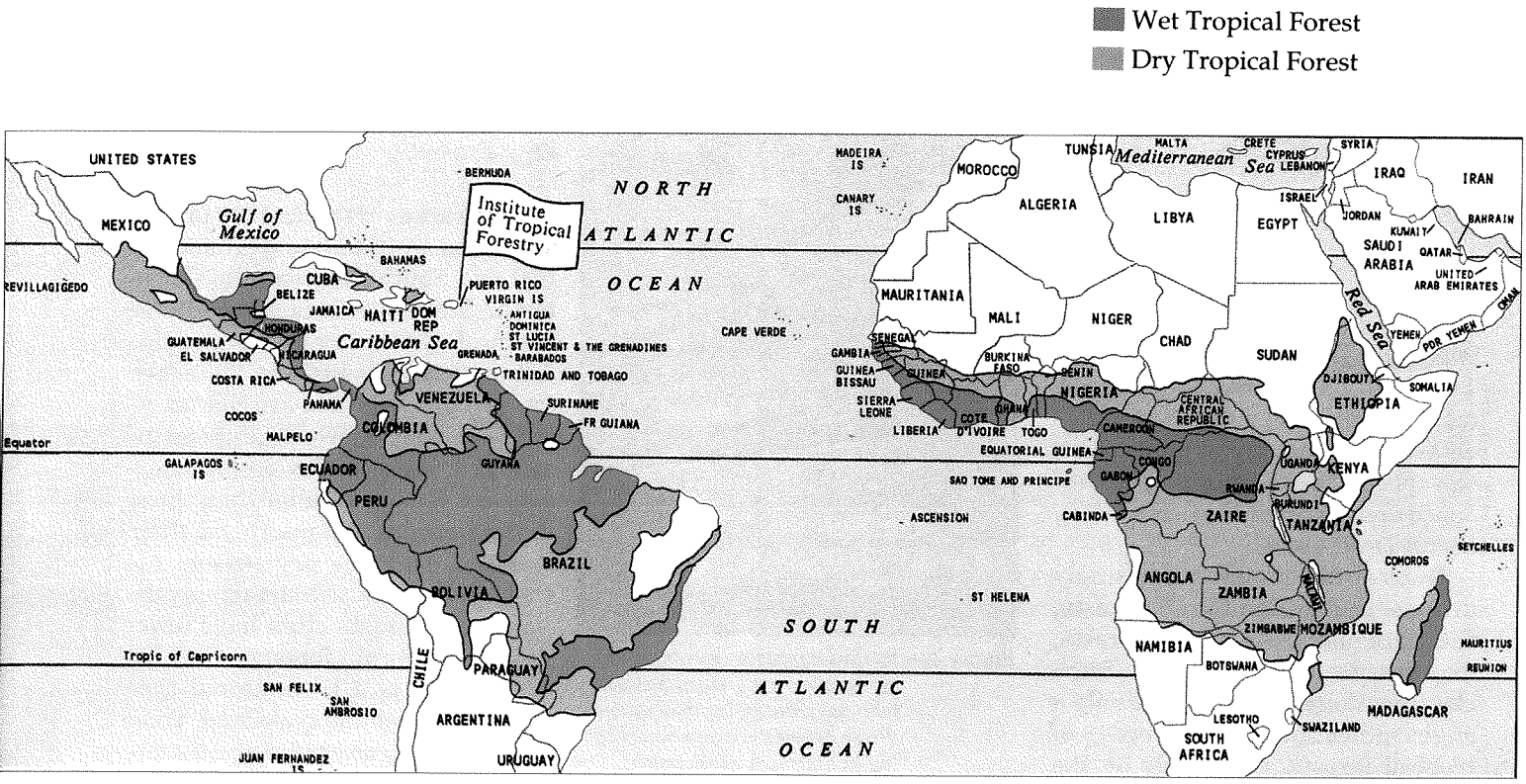


Figure 1.— *The worldwide distribution of tropical wet (green) and dry (gold) forests.*

Figure. 2— *The African tulip tree (*Spathodea campanulata*) was spread around the world as an ornamental and now grows in disturbed natural forests in Puerto Rico and other moist tropical countries.*





INTRODUCTION

The world's tropical forests circle the globe in a ring around the Equator. They are surprisingly diverse, ranging from lush rain forests to dry savannas and containing millions of species of plants and animals (fig. 1). Tropical forests once covered some 15.3 billion acres (6.2 billion ha). In recent times, however, they have been cut at a rapid rate to make room for agriculture and to obtain their many valuable products. Between 1985 and 1990, 210 million acres (85 million ha) of tropical forests were destroyed.

This guide shows how modern forest practices can help stem the tide of forest destruction while providing valuable forest products for people. The tropical forests of Puerto Rico, which were abused for centuries, were badly depleted by the early 1900's. Widespread abandonment of poor agricultural lands has allowed natural reforestation and planting programs to create a patchwork of private, Commonwealth, and Federal forests across the land (fig. 2). The most frequent example in this publication is the Luquillo Experimental Forest, which could be a model for protecting and managing tropical forests worldwide.

TYPES OF TROPICAL FORESTS

About half of all the world's forests are in the Tropics, the area between the Tropic of Cancer and the Tropic of Capricorn. This region may be best known for its rain forests—lush, steamy jungles with towering trees, epiphytes, and dense understories of smaller trees, shrubs, and vines.

Tropical forests are surprisingly diverse. In addition to rain forests, there are mangroves, moist forests, dry forests, and savannas. Such classifications, however, give only a slight indication of the diversity of tropical forests. One study by the Food and Agriculture Organization (FAO) of the United Nations, which considered 23 countries in tropical America, 37 in tropical Africa, and 16 in tropical Asia, identified dozens of types of tropical forests: open and closed canopy forests, broad-leaved trees and conifer forests, closed forests and mixed forest-grasslands, and forests where agriculture has made inroads.

Rain Forests

The largest remaining areas of tropical rain forests are in Brazil, Congo, Indonesia, and Malaysia. Precipitation generally exceeds 60 inches (150 cm) per year and may be as high as 400 inches (1000 cm). Lowland rain forests are among the world's most productive of plant communities. Giant trees may tower 200 feet (60 m) in height and support thousands of other species of plants and animals. Montane (mountain) rain forests grow at higher elevations where the climate is too windy and wet for optimum tree growth.

Figure 3.— *Wetland forests (swamps and mangroves) are critical habitats for many plant and animal species. Whole wetland ecosystems are being lost through development.*

Mangrove forests grow in the swampy, intertidal margin between sea and shore and are often considered part of the rain forest complex. The roots of mangrove trees help stabilize the shoreline and trap sediment and decaying vegetation that contribute to ecosystem productivity (fig. 3).

Dry Forests

Large areas of tropical dry forests are found in India, Australia, Central and South America, the Caribbean, Mexico, Africa, and Madagascar. Dry forests receive low rainfall amounts, as little as 20 inches (50 cm) per year, and are characterized by species well adapted to drought. Trees of dry tropical forests are usually smaller than those in rain forests, and many lose their leaves during the dry season. Although they are still amazingly diverse, dry forests often have fewer species than rain forests.

Savanna is a transitional type between forest and grassland. Trees are often very scattered and tend to be well adapted to drought and tolerant of fire and grazing. If fire is excluded, trees eventually begin to grow and the savanna is converted to dry forest. With too much fire or grazing, dry forest becomes savanna (fig. 4). This vegetation type has fewer species of trees and shrubs but more grasses and forbs than other forest types in the Tropics.

Figure 4.— *Tropical grasslands and savannas are created from tropical dry forests by fire and to a lesser extent by grazing. In the absence of fire, dry forest reinvades grasslands and savannas.*

VALUE OF TROPICAL FORESTS

All forests have both economic and ecological value, but tropical forests are especially important in global economy. These forests cover less than 6 percent of the Earth's land area, but they contain the vast majority of the world's plant and animal genetic resources. The diversity of life is astonishing. The original forests of Puerto Rico, for example, contain more than 500 species of trees in 70 botanical families. By comparison, temperate forests have relatively few. Such diversity is attributed to variations in elevation, climate, and soil, and to the lack of frost.

There is also diversity in other life forms: shrubs, herbs, epiphytes, mammals, birds, reptiles, amphibians, and insects. One study suggests that tropical rain forests may contain as many as 30 million different kinds of plants and animals, most of which are insects (fig. 5).

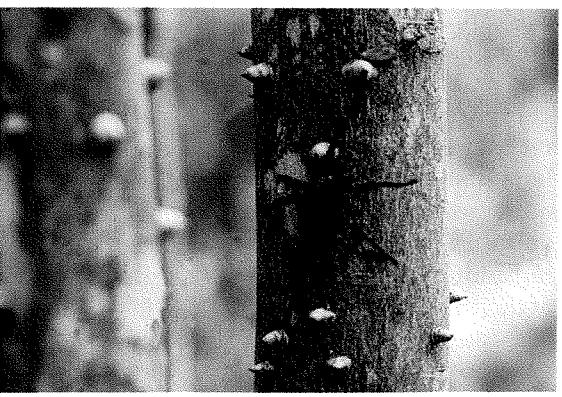


Figure 5.— *The number of arthropod species is far greater than the number of species of all other life forms combined. The majority of arthropods are tropical.*

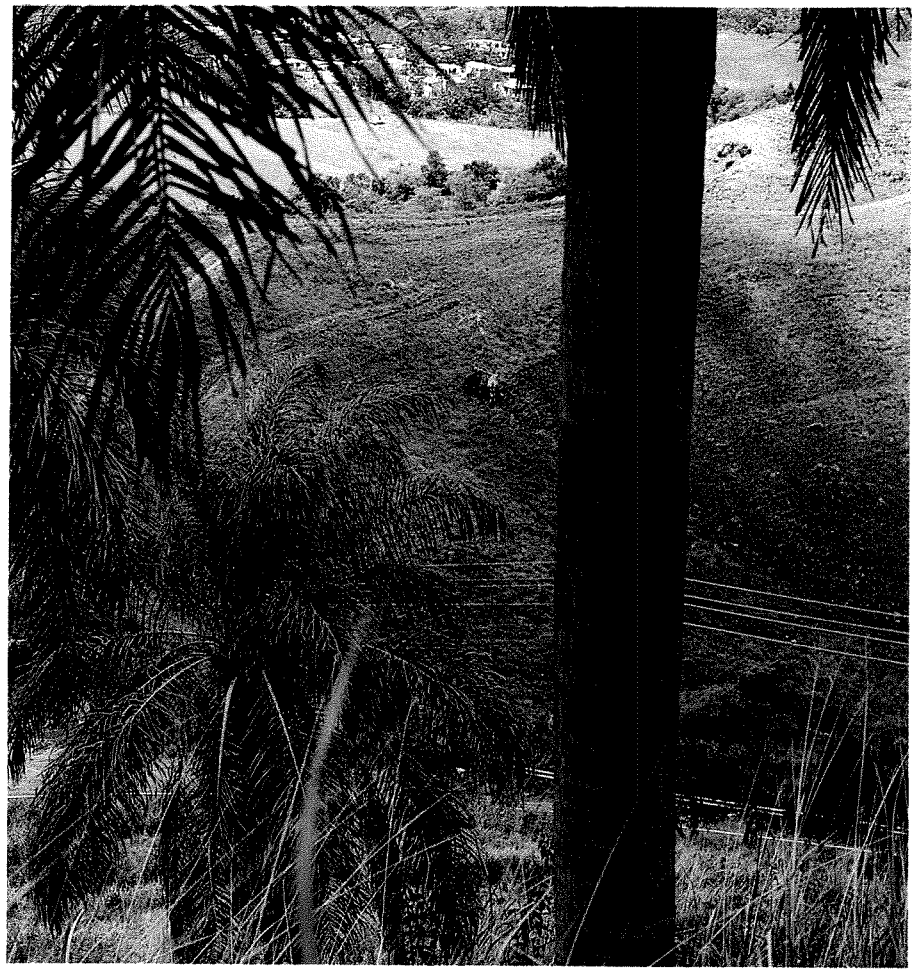


Figure 6. — *Harvest of wood products from the tropical forests is essential to maintain our present lifestyle, but it should be planned and conducted carefully to prevent damage to the environment and loss of productivity of the land.*

Wood and Other Products

Tropical forests provide many valuable products including rubber, fruits and nuts, meat, rattan, medicinal herbs, floral greenery, lumber, firewood, and charcoal. Such forests are used by local people for subsistence hunting and fishing. They provide income and jobs for hundreds of millions of people in small, medium, and large industries.

Tropical forests are noted for their beautiful woods (fig. 6). Four important commercial woods are mahogany, teak, melina, and okoumé. Honduras mahogany (*Swietenia macrophylla*), grows in the Americas from Mexico to Bolivia. A strong wood of medium density, mahogany is easy to work, is long lasting, and has good color and grain. It is commonly used for furniture, molding, paneling, and trim. Because of its resistance to decay, it is a popular wood used in boats. Teak (*Tectona grandis*) is native to India and Southeast Asia. Its wood has medium density, is strong, polishes well, and has a warm yellow-brown color. Also prized for resistance to insects and rot, teak is commonly used in cabinets, trim, flooring, furniture, and boats (fig. 7). Melina (*Gmelina arborea*) grows naturally from India through Vietnam. Noted

Figure 7.— *Teak* (Tectona grandis) *is one of the most valuable tropical hardwoods. This young plantation is growing in St. Croix, U.S. Virgin Islands.*

for fast growth, melina has light-colored wood that is used mainly for pulp and particleboard, matches, and carpentry. Okoumé (*Aucoumea klaineana*) is native to Gabon and the Congo in west Africa. A large, fast-growing tree, the wood has moderately low density, good strength-to-density ratio, and low shrinkage during drying. It is commonly used for plywood, paneling, interior furniture parts, and light construction.

Other Economic Values

Tropical forests are home for tribal hunter-gatherers whose way of life has been relatively unchanged for centuries. These people depend on the forests for their livelihood. More than 2.5 million people also live in areas adjacent to tropical forests. They rely on the forests for their water, fuelwood, and other resources and on its shrinking land base for their shifting agriculture. For urban dwellers, tropical forests provide water for domestic use and hydroelectric power. Their scenic beauty, educational value, and opportunities for outdoor recreation support tourist industries.

Many medicines and drugs come from plants found only in tropical rain forests. Some of the best known are quinine, an ancient drug used for malaria; curare, an anesthetic and muscle relaxant used in surgery; and rosy periwinkle, a treatment for Hodgkin's disease and leukemia. Research has identified other potential drugs that may have value as contraceptives or in treating a multitude of maladies such as arthritis, hepatitis, insect bites, fever, coughs, and colds. Many more may be found. In all, only a few thousand species have been evaluated for their medicinal value.

In addition, many plants of tropical forests find uses in homes and gardens: ferns and palms, the hardy split-leaf philodendron, marantas, bromeliads, and orchids (fig. 8), to name just a few.

DEFORESTATION

Environmental Benefits

Tropical forests do more than respond to local climatic conditions; they actually influence the climate. Through transpiration, the enormous number of plants found in rain forests return huge amounts of water to the atmosphere, increasing humidity and rainfall, and cooling the air for miles around. In addition, tropical forests replenish the air by utilizing carbon dioxide and giving off oxygen. By fixing carbon they help maintain the atmospheric carbon dioxide levels low and counteract the global "greenhouse" effect.

Forests also moderate streamflow. Trees slow the onslaught of tropical downpours, use and store vast quantities of water, and help hold the soil in place. When trees are cleared, rainfall runs off more quickly, contributing to floods and erosion.

Before the dawn of agriculture approximately 10,000 years ago, forests and open woodland covered about 15.3 billion acres (6.2 billion ha) of the globe. Over the centuries, however, about one-third of these natural forests has been destroyed. According to a 1982 study by FAO, about 27.9 million acres (11.3 million ha) of tropical forests are cut each year—an area about the size of the States of Ohio or Virginia. Between 1985 and 1990, an estimated 210 million acres (85 million ha) of tropical forests were cut or cleared. In India, Malaysia, and the Philippines, the best commercial forests are gone, and cutting is increasing in South America. If deforestation is not stopped soon, the world will lose most of its tropical forests in the next several decades.

Figure 8.— *Cultivated orchids of today were selected and bred from tropical forest species. This* Vanda *sp. probably originated in Southeast Asia.*

Reasons for Deforestation

Several factors are responsible for deforestation in the Tropics: clearing for agriculture, fuelwood cutting, and harvesting of wood products. By far the most important of these is clearing for agriculture. In the Tropics, the age-old practice of shifting, sometimes called "slash-and-burn," agriculture has been used for centuries. In this primitive system, local people cut a small patch of forest to make way for subsistence farming. After a few years, soil fertility declines and people move on, usually to cut another patch of trees and begin another garden.

In the abandoned garden plot, the degraded soil at first supports only weeds and shrubby trees. Later, soil fertility and trees return, but that may take decades. As population pressure increases, the fallow (rest) period between cycles of gardening is shortened, agricultural yields decrease, and the forest region is further degraded to small trees, brush, or eroded savanna.

Conversion to sedentary agriculture is an even greater threat to tropical forests. Vast areas that once supported tropical forests are now permanently occupied by subsistence farmers and ranchers and by commercial farmers who produce sugar, cocoa, palm oil, and other products.

In many tropical countries there is a critical shortage of firewood. For millions of rural poor, survival depends on finding enough wood to cook the evening meal. Every year more of the forest is destroyed, and the distance from home to the forest increases. Not only do people suffer by having to spend much of their time in the search for wood, but so does the land. Damage is

greatest in dry tropical forests where firewood cutting converts forests to savannas and grasslands.

The global demand for tropical hardwoods, an $8-billion-a-year industry, also contributes to forest loss. Tropical forests are usually selectively logged rather than clearcut. Selective logging leaves the forest cover intact but usually reduces its commercial value because the biggest and best trees are removed. Selective logging also damages remaining trees and soil, increases the likelihood of fire, and degrades the habitat for wildlife species that require large, old trees—the ones usually cut. In addition, logging roads open up the forests to shifting cultivation and permanent settlement.

In the past, logging was done primarily by primitive means—trees were cut with axes and logs were moved with animals such as oxen. Today the use of modern machinery—chain saws, tractors, and trucks—makes logging easier, faster, and potentially more destructive.

Figure 9.— *The rare and endangered Puerto Rican parrot (*Amazona vittata*) is found today in small wild and captive flocks in the Luquillo Experimental Forest.*

Endangered Wildlife

Forests are biological communities—complex associations of trees with other plants and animals that have evolved together over millions of years. Because of the worldwide loss of tropical forests, thousands of species of birds and animals are threatened with extinction. The list includes many unique and fascinating animals, among them the orangutan, mountain gorilla, manatee, jaguar, and Puerto Rican parrot. Although diverse and widely separated around the globe, these species have one important thing in common. They, along with many other endangered species, rely on tropical forests for all or part of their habitat.

Orangutans (*Pongo pygmaeus*) are totally dependent on small and isolated patches of tropical forests remaining in Borneo and Sumatra, Indonesia. Orangutans spend most of their time in the forest canopy where they feed on leaves, figs and other fruit, bark, nuts, and insects. Large trees of the old-growth forests support woody vines that serve as aerial ladders, enabling the animals to move about, build their nests, and forage for food. When the old forests are cut, orangutans disappear.

The largest of all primates, the gorilla, is one of man's closest relatives in the animal kingdom. Too large and clumsy to move about in the forest canopy, the gorilla lives on the forest floor where it forages for a variety of plant materials. Loss of tropical forests in central and west Africa is a major reason for the decreasing numbers of mountain gorillas (*Gorilla gorilla*). Some habitat has been secured, but the future of this gentle giant is in grave danger as a result of habitat loss and poaching.

The jaguar (*Leo onca*), a resident of the Southwestern United States and Central and South America, is closely associated with forests. Its endangered status is the result of hunting and habitat loss.

The Puerto Rican parrot (*Amazona vittata*), a medium-sized, green bird with blue wing feathers, once inhabited the entire island of Puerto Rico and the neighboring islands of Mona and Culebra. Forest destruction is the principal reason for the decline of this species. Hunting also contributed. Today, only a few Puerto Rican parrots remain in the wild and their survival may depend on the success of a captive breeding program (fig. 9).

In addition to species that reside in tropical forests year round, others depend on such forests for part of the year. Many species of migrant birds journey 1,000 miles or more between their summer breeding grounds in the north and their tropical wintering grounds. These birds are also threatened by tropical forest destruction.

THE PRACTICE OF FORESTRY

Forestry—loosely defined as the systematic management and use of forests and their natural resources for human benefit—has been practiced for centuries. Most often, forestry efforts have been initiated in response to indiscriminate timber cutting that denuded the land and caused erosion, floods, or a shortage of wood products.

Ancient Forestry Practices

In ancient Persia (now Iran), forest protection and nature conservation laws were in effect as early as 1,700 B.C. Two thousand years ago the Chinese practiced what they called "four sides" forestry—trees were planted on house side, village side, road side, and water side. More than 1,000 years ago, Javanese maharajahs brought in teak and began to cultivate it. In the African Tropics, agroforestry (growing of food crops in association with trees) has been practiced for hundreds of years.

In the Yucatan Peninsula of southern Mexico, the ancient Mayas cultivated fruit and nut trees along with such staples as corn, beans, and squash. Bark, fibers, and resin were obtained from plants grown in fields, kitchen gardens, and orchards. Early in their civilization, the Mayas practiced slash-and-burn agriculture. As their population grew, they found more efficient methods of growing crops. They terraced hillsides, learned how to decrease the time between "rotations" of agricultural land with native forests, dug drainage channels and canals to move water to and from cultivated areas, and filled in swampland to plant crops.

The agricultural sophistication of the Mayas enabled their civilization to grow and flourish. What brought about their decline about A.D. 820 is not fully known, but some believe that as their society developed, the Mayas made unsustainable demands on their environment.

Relatively little is known about tropical forestry before the mid-1800's in most places. At that time, the European colonial empires—notably the Dutch, English, and Spanish—brought modern forest management practices to Indonesia, India, Africa, and the Caribbean. Centers for forestry and forestry research were established, and more careful records were kept.

Sustainable Forestry

Modern forestry has its basis in 18th-century Germany. Like the Chinese and the Mayan forest practices, German forestry is essentially agricultural. Trees are managed as a crop. Two concepts are important: renewability and sustainability. Renewability means that trees can be replanted and seeded and harvested over and over again on the same tract of land in what are known as crop "rotations." Sustainability means that forest harvest can be sustained over the long term. How far into the future were foresters expected to plan? As long as there were vast acres of virgin (original) forests remaining, this question was somewhat academic. Today, however, sustainability is a vital issue in forestry. Most of the world's virgin forests are gone, and people must rely more and more on second- growth or managed forests. Perhaps we now face, as never before, the limits to long-term productivity.

In the German forest model, forestry is viewed as a continual process of harvest and regeneration. Harvest of wood products is a goal, but a forester's principal tasks are to assure long-term productivity. That is achieved by cutting the older, mature, and slow-growing timber to make way for a new crop of young, fast-growing trees.

Harvest-Regeneration Methods

Three examples of timber harvest-regeneration methods (silvicultural systems) illustrate how foresters manage stands to produce timber on a sustained basis.

Selection

Individual trees or small groups of trees are harvested as they become mature. Numerous small openings in the forest are created in which saplings or new seedlings can grow. The resulting forest has a continuous forest canopy and trees of all ages. Such systems favor slow-growing species that are shade tolerant.

Clearcutting

In clearcutting, an entire stand of trees is removed in one operation. From the forester's point of view, clearcutting is the easiest way to manage a forest—and the most economical. Regeneration may come from sprouts on stumps, from seedlings that survive the logging operation, or from seeds that germinate after the harvest. If natural regeneration is delayed longer than desired, the area is planted or seeded.

Clearcutting systems are often used to manage fast-growing species that require a lot of light. Resulting stands are even aged because all the trees in an area are cut—and regenerated—at the same time. Clearcutting has become controversial in

recent years because it has the potential to damage watersheds and because it tends to eliminate species of wildlife dependent on old-growth trees. If clearcuts are kept small and the cutting interval is long enough, however, biological diversity may not be impaired.

Shelterwood

In shelterwood systems, the forest canopy is removed over a period of years, usually in two cuttings. After the first harvest, natural regeneration begins in the understory. By the time the second harvest is made, enough young trees have grown to assure adequate regeneration. Shelterwood systems favor species that are intermediate in tolerance to shade. Such systems are difficult to use successfully and are the least used of the three silvicultural methods described.

Multiple-Use Forestry

Gifford Pinchot, the first Chief of the U.S. Forest Service, was also this country's first professional forester. Pinchot advocated the use of forest resources—all resources, not just timber—for human benefit. Pinchot was a strong and charismatic leader, and his ideas helped shape the course of forestry in the United States.

Pinchot had a vocal opponent in John Muir, a young naturalist from California who believed that public lands should be preserved rather than used. Eventually Muir and Pinchot became rivals for public approval. Oddly enough, there was no loser in this early conservation battle. Muir's preservation ethic became embodied in the philosophy of the National Parks, and Pinchot's concept of wise use became the guiding principle of the National Forests.

National Forests are still managed under the concepts of multiple use and sustained yield. The dominant uses of National Forests are considered to be wood, water, wildlife, forage (for domestic cattle and wildlife), and recreation. Extraction of minerals and other valuable products is also considered a legitimate use of National Forests. Because Pinchot's philosophy left room for the "highest and best use" of a given area, the U.S. National Forests now include a wilderness system of more than 32 million acres (13 million ha) in which timber harvest is not allowed.

Today it is generally recognized that most, if not all, nondestructive uses of forest are valid. Some areas may be set aside as parks; others for wildlife habitat or as wilderness. Still others will be managed for timber harvest or multiple benefits. Today, conflicts arise primarily over where these different uses will be dominant. In the National Forests, such decisions are made through a land-use planning process in which the public has ample opportunities for input and involvement.

FORESTRY RESEARCH

At the turn of the century, very little was known about the world's native forests or how to manage them. In the United States, foresters were quick to recognize the value of information about forests and a branch of research was established in the Forest Service in 1915. Early research was done primarily in support of reforestation efforts, but, as forestry grew in size and complexity, so did the research.

Today, the USDA Forest Service has six regional experiment stations located in important forest regions. Each experiment station has several field laboratories generally with specialized assignments for a geographic region or a specific subject area, and numerous sites for field research. In addition, the Forest Products Laboratory in Madison, WI, serves as a nationwide center for research and development of new technology relating to wood, including tropical woods. Two laboratories are dedicated exclusively to tropical forest research: the International Institute of Tropical Forestry in Puerto Rico and the Institute of Pacific Islands Forestry in Hawaii.

Research is vital for modern forest management, which is information intensive. Today's foresters require vast quantities of data and a knowledge of ecology: they must understand not only the parts of ecosystems but how different parts of the environment interact. Scientific investigations are conducted in support of all kinds of forestry activities: silviculture, forest insect and disease control, wildlife habitat management, fire prevention and control, range and watershed management, forest products utilization, forest survey, reforestation, ecology, and economics.

TROPICAL FORESTRY

In the past, timber harvest in the Tropics has seldom been followed by regeneration. Conversion to agriculture is often permanent or results in soil erosion. Timber harvest contracts have usually been short term and have provided little or no incentive for timber companies to replant. So little reforestation has been done in the Tropics that many people believe these forests cannot be restored. However, there are many examples of successful reforestation in India, Indonesia, and the Caribbean.

In the Tropics, as elsewhere, forestry is a mixture of modern innovations and ancient techniques borrowed from local tradition. Plantation forestry is common. Forest reserves have been established for timber harvest, wildlife habitat, scenery, outdoor recreation, or watershed protection. And in the Tropics, agroforestry—tree growing combined with agricultural cropping—is much more common than elsewhere.

Figure 10.—*Forest scientists are working to determine which trees will grow well in plantations and how best to manage them.*

Plantation Forestry

In the Tropics, trees are often planted and grown in plantations for wood production. Often, many species must be tried to determine which will grow best (fig. 10). Plantations must also be supported by major investments in forest management and research. Forest nurseries must be established, and planting techniques and cultural practices (spacing and thinning, pruning, fertilization, insect and disease control, and genetic improvement) must be developed.

Extensive pine plantations have been established in the moist Tropics, mainly in South Africa and Australia. Species most often planted include Caribbean pine (*Pinus caribaea*), ocote pine (*P. oocarpa*), slash pine (*P. elliottii*), and benguet pine (*P. kesiya*). Pines are popular plantation trees because they are generally fast growing, have good survival rates, and are adapted to a wide variety of environments, including degraded forest sites.

Eucalypts, including species such as *Eucalyptus grandis, E. deglupta, E. tereticornis, E. globulus,* and *E. camaldulensis* are favored for the same reasons. Eucalypts are commonly grown for pulp, fuel, and lumber. Other species commonly planted include teak (*Tectona grandis*), Honduras mahogany (*Swietenia macrophylla*), melina (*Gmelina arborea*), beefwood (*Casuarina equisetifolia*), and Mexican cypress (*Cupressus lusitanica*).

Forest Reserves

There are many reasons for establishing forest reserves in the Tropics. They can restore watersheds and wildlife habitat, improve scenic beauty and opportunities for outdoor recreation, and produce wood and other products for local use and export. Many forest products contribute to the sustenance and income of local people: wildlife and fish, firewood, rubber, fruits and nuts, rattan, medicinal herbs, floral greenery, and charcoal.

Perhaps the most famous of these reserves is the 5,600 square mile (14,500 k^2) Serengeti National Park in Tanzania. With its vast herds of grazing ungulates (hoofed animals) and predators, including several endangered species, the Serengeti is a showcase of a savanna ecosystem that has long been protected and managed for wildlife and other natural resources (fig. 11). Although plagued with poachers, the Serengeti promotes the cause of wildlife conservation to the many thousands of "ecotourists" who pay to experience nature each year.

Another type of forest reserve is the "extractive" reserve, which is dedicated to the production of useful products. Large reserves of this type have been established recently in Brazil. Local residents use them for tapping rubber, for gathering fruits and nuts, for hunting, and for harvesting wood on a sustained-yield basis. Such uses provide a sustainable income while maintaining the ecological integrity of the forest.

Figure 11.— *Giraffes (*Giraffe cameloparadalis*) are dependent on* Acacia *spp. and other savanna trees and shrubs for sustenance. (photo by Ariel Lugo).*

Agroforestry

The practice growing of trees in combination with agricultural crops is fairly common in the Tropics. It is possible to grow food crops year around in many forested areas, and rural poor depend on this source of food as nowhere else on Earth.

Taungya System

Various systems have been developed for combining forestry with agriculture. "Taungya" is a Burmese word meaning cultivated hill plot. This system of agroforestry was developed in Europe during the Middle Ages and probably independently in a number of places in the Tropics. After existing forest or ground cover is removed by burning, trees are planted along with agricultural crops. Both are cultivated until the tree canopy closes. Then the area is left to grow trees, and another site is located for combined forestry-agriculture.

Shade Cropping

An overstory of trees is often used to provide shade for agricultural crops. A common practice is to grow tree species such as guaba (*Inga vera*) over coffee. In Puerto Rico, many forests developed where coffee was once grown in this manner.

Support Crops

Trees can be planted to provide support (and sometimes shade) for vine crops. Vines such as pepper and vanilla need support.

Alley Cropping

Nitrogen-fixing trees are planted in hedges in widely-space parallel rows along the contour of slopes. Food crops are grown in the "alley" between the rows. The trees add nitrogen and organic matter, protect the soil from erosion, and provide wood and animal forage.

Living Fences

Green fenceposts that will root and sprout often are planted in a closely spaced row. When they sprout, they create a "living fence" that provides shade and forage for cattle.

Windbreaks

Trees are often planted as windbreaks for agricultural crops, farms, or homesites. Such plantings can eventually contribute wood products as well as shelter. Food trees such as citrus, rubber, and mango can also provide fuel, lumber, and other wood products when they have outlived their original usefulness.

NEW DIRECTIONS IN TROPICAL FORESTRY

The conservation issues of the past seem simple compared with those of today. As we move toward the 21st century, human societies are concerned with global warming, deforestation, species extinction, and rising expectations. Growing populations must be fed, clothed, and sheltered, and people everywhere want higher standards of living.

Global Warming

Warming of the earth's atmosphere is a major environmental issue. Air pollution, deforestation, and widespread burning of coal, oil, and natural gas have increased atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons. These gases trap heat from the sun and prevent it from radiating harmlessly back into space. Thus, the "greenhouse" or warming effect is created.

Because of natural variations in climate, it is difficult to measure warming over large areas. Scientists agree, however, that increases in atmospheric concentrations of greenhouse gases will cause higher temperatures worldwide. Even an increase of a few degrees might cause serious melting of the polar icecaps, a gradual rise in sea level, a disruption in normal weather patterns, a possible increase in forest fires, and the extinction of species.

Role of Forests

Trees, the largest of all land plants, act as a kind of environmental "buffer" for the ecosystem they dominate. They help ameliorate the extremes of climate (heat, cold, and wind) and create an environment where large land mammals, including people, can live comfortably.

Trees complement animals in the global environment. Mammals take in oxygen from the air and exhale carbon dioxide. Plants use the carbon dioxide in their growth processes, store the carbon in woody tissues, and return oxygen to the atmosphere as a waste product. This process, known as photosynthesis, is essential to life. Carbon captured from the atmosphere by photosynthesis is eventually recycled through the environment in a process known as the carbon cycle. Trees have an especially important role in the carbon cycle.

Tree leaves also act as filters to remove atmospheric pollutants from the air. This effect is particularly beneficial in urban areas.

Forestry Issues

Two key issues will dominate forestry in the years ahead: (1) maintaining long-term productivity of managed forests, and (2) preventing further loss of tropical forests. Both problems will require new approaches to forest management.

Traditionally, forestry has focused on growing crops of wood in plantations or in managed natural stands. In this "agricultural mode," other benefits of forest such as watershed protection, wildlife habitat, climate moderation, and outdoor recreation, have received less attention than wood production.

Perhaps more importantly, the sustainability of the full range of forest benefits has not been mea-

sured. There is no question that trees can be grown for crops of wood in managed stands. With intensive management—short rotations, species selection, genetic improvement, fertilization, thinning, and other cultural treatments—more wood can be produced in less time than in natural forests. But for how long? And at what cost in other benefits?

As more and more of the world's original forests have been cut, the ecological value of forests has come to be more appreciated. In recent years, increased emphasis has been put on what some are calling "ecosystem management." In this model, the health and long-term stability of the forest are paramount, and timber production is considered a byproduct of good forest management rather than the principal product. In Puerto Rico, for example, wood production is a relatively minor aspect of forestry. Since the 1930's when timber harvests were curtailed, the forests have been managed primarily for watershed protection, wildlife habitat, and outdoor recreation.

There are no easy solutions to the problem of tropical forest destruction, but most experts agree that the problems cannot be solved simply by locking up the forests in reserves. The forests are too important to local people for that to be a workable solution. There is no doubt that tropical forests will be cut. It is better for them to be cut in an ecologically sound manner than to be cleared for poor-quality farmland or wasted by poor harvest practices (fig. 12).

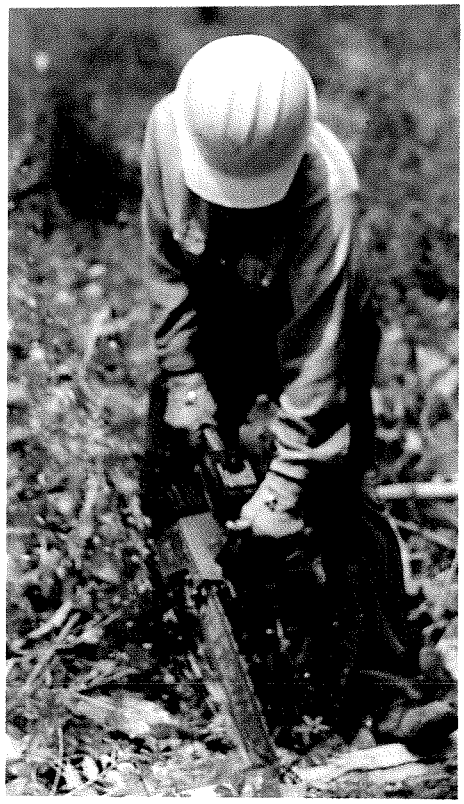


Figure 12.— *Vast areas of tropical forests have been and are still being converted to marginally productive farmland to feed a growing population.*

The only real long-term solutions are: (1) more efficient agriculture on suitable farmland, (2) efficient forestry practice including plantations, and (3) reserves to protect species and ecosystems. Many forestry experts believe that we have only begun to tap the potential for wise use of tropical forests. Many uses have yet to be fully explored. We are only starting to learn the value of tropical forests for medicines, house and garden plants, food and fiber, tourism, and natural resource education.

From Mt. Britton Tower at an elevation of 3,088 feet (941 m) in the heart of the rugged Luquillo Mountains of northeastern Puerto Rico, the landscape spreads out in a green and glorious panorama. Thousands of people each year hike this trail for the splendid view of the Luquillo Forest.

LUQUILLO EXPERIMENTAL FOREST

A Managed Forest in the Tropics

If the clouds lift, even momentarily, El Yunque rock is visible to the northeast. At 3,469 feet (1,058 m) in elevation, El Yunque is the second highest peak in the Luquillo Experimental Forest and the highest point visible on the horizon. According to local legend, the Taino Indians thought of El Yunque as a place of transcendence. With the clouds almost constantly drifting over the mountain and the stillness and beauty of the place, it is easy to see why they felt that way.

From the tower, the town of Luquillo is visible to the north. Far to the northwest is Isla Verde on the outskirts of San Juan—just a speck on the horizon. But mostly there is forest. A warm climate and as much as 240 inches (610 cm) of rain a year have produced a dense evergreen forest rich in native flora and fauna —225 native tree species, a vast assortment of vines, ferns, tree ferns, and mosses, and more than 100 different vertebrates. Thirty-five species are endemic—meaning that they occur nowhere else. Of these, five are considered threatened or endangered, including the beautiful and rare Puerto Rican parrot.

Forest Types

From Mt. Britton, four of Puerto Rico's distinct forest types can be seen: tabonuco, palo colorado, sierra palm, and dwarf forest.

Tabonuco forest is dominated by the tabonuco tree (*Dacryodes excelsa*) and grows primarily in protected sites at low elevations. Tabonuco forest has many of the characteristics for which tropical rain forests are noted. The forest canopy has three levels: an upper level that may be as much as 35 percent tabonuco, a lower canopy, and an understory. The second most prominent tree in this forest type, the motillo (*Sloanea berteriana*), has large buttress roots typical of many rain forest trees. Such roots help support the heavy canopy of trees that grow in very wet soil. The forest floor is only sparsely vegetated, but the canopy is rich with aerial plants: bromeliads, orchids, vines, and arborial ferns.

Above 2,000 feet (600 m) in elevation is the palo colorado forest. It takes its name from the palo colorado (*Cyrilla racemiflora*) (fig. 13), a tree also found in South and Central America and in the Southeastern United States. Tree height in the palo colorado forest is less than 50 feet (15 m), and the layers of the forest canopy are less distinct than in the tabonuco type.

At about the same elevation as the palo colorado forest, but on steeper slopes, are the sierra palm forests dominated by the sierra palm (*Prestoea montana*). Sometimes called palm-brake, this forest type may reach 50 feet (15 m) in height.

Figure 13.— *Palo colorado* (Cyrilla racemiflora) *is a key species in the Luquillo rain forest.*

At the highest elevations, near the top of El Yunque, grows the elfin forest, also called the cloud forest, dwarf forest, or mossy forest. This forest type is composed of dense stands of small, stunted trees and shrubs. The elfin forest has many of the same tree species as the palo colorado, but their growth is limited by adverse climate—heavy rain, wind, and almost constant cloud cover.

Forest Decline

From Mt. Britton, the forest seems to stretch forever. However, this is only an illusion. Very little is left of the magnificent forests that once covered the island of Puerto Rico. Since they were first seen by Christopher Columbus on his second voyage to the New World in 1493, Puerto Rican forests have been subjected to intensive use and abuse. With increasing population, the forests were cleared to make way for human settlements, farms, coffee plantations, and other agricultural crops. By the early 1900's, probably 85 percent of the original forests were gone.

The lowland ausubo forests were the first to be cut. Very little of that forest type remains. The tabonuco forest was once an important habitat of the Puerto Rican parrot, and destruction of much of this forest type is a likely cause of the species' decline. The parrot, a beautiful green bird with bright-blue wing feathers, is now rarely seen. It survives only in small numbers in an isolated area of the Luquillo Forest and in a captive population used for breeding purposes.

More of the palo colorado type remains, but in the 1940's and 1950's, many of the large, old palo colorado trees were selectively cut for charcoal or to encourage growth of trees more valuable for timber. This destruction occurred before scientists learned that the parrot nests in these trees.

Early Conservation Efforts

As in other parts of the world, widespread forest cutting in Puerto Rico eventually led to conservation efforts. The sale of wood was restricted by the Spanish in 1816, primarily because some species were considered necessary for naval use during the colonial wars for independence. In 1824, alarmed by the extent of deforestation, Governor Miguel De la Torre issued a decree to plant trees for watershed improvement—the first real conservation law. Spain drafted its first comprehensive forest laws in 1839 and set up forestry commissions that led to the first forest inventory on the island in 1843.

In the next several decades, government protection of the forests decreased, but enough interest in conservation remained for King Alfonso XII to create the first forest reserves in 1876. Their purposes were to ensure water quality, to prevent soil erosion, and to assure an adequate supply of wood for roofing material, fuelwood, and sawtimber.

Because of those early set-asides and later purchases, Puerto Rico now has a fine system of Commonwealth Forests. These forests are administered by the Department of Natural Resources, an agency of the Commonwealth of Puerto Rico. Although small, they are widely scattered around the island and preserve representative samples of several native forest types (mangroves, dry forests, and rain forests) as well as plantations of pine, mahogany, and teak.

Three-fourths of Puerto Rico's forests are privately owned. A few plantations of pine and mahogany have been established, but most forests have regenerated naturally on abandoned farmland. Today, nearly 35 percent of Puerto Rico is forested. These forests give Puerto Rico much of its current beauty and may someday be a rich source of timber and other forest products.

A Forest of Many Names

Luquillo Forest contains land that was part of the original forest reserves set aside by the Spanish in 1876. Originally just 12,400 acres (5,020 ha), this reserve now covers more than 28,000 acres (11,300 ha). It includes the largest block of undisturbed forest on the island. Unique in the Tropics, Luquillo Forest is the oldest forest reserve in the National Forest System and has been under some form of management for more than 100 years.

The reserve is managed by the U.S. Department of Agriculture, Forest Service, and has two primary functions—management and research. Thus, its two names: Luquillo Experimental Forest and Caribbean National Forest. Actually, the forest has had many names over the years, names that reflect a long and colorful history. First called El Yunque after a prominent peak in the vicinity, the name was changed in 1903 to Luquillo Forest Reserve and again in 1935 to Caribbean National Forest (in Spanish, "Bosque Nacional del Caribe"). In 1956, the Forest was designated as the Luquillo Experimental Forest in recognition of the growing importance of research in the reserve. Often, however, the forest is simply referred to as "El Yunque, its oldest and perhaps most picturesque name.

The Caribbean National Forest is part of the National Forest System and is managed by law for multiple-use benefits. Areas within the forest are dedicated to what is considered their best uses—whether for outdoor recreation, watershed protection, wildlife habitat, or growing trees.

Outdoor Recreation

In the forest, there are many opportunities for outdoor recreation. The coolness of the mountains draws people from the urban centers of San Juan and other towns in the warm and humid coastal lowlands. Access is excellent. From San Juan, the Caribbean National Forest is less than an hour's drive on paved roads. Three highways traverse the Forest: one on the northeastern boundary, another along the western edge, and still another through the interior that provides access to El Yunque Recreation Area with its many foot trails and picnic shelters. For visitors, the first contact with the Forest Service is often with interpretive displays and a fine film at the splendid new visitors center "El Portal del Yunque" near the entrance of the forest on Highway 191. Interpretive naturalists are stationed at several points in the forest to assist visitors and to point out local features of interest.

Watershed Protection

Eight major rivers have their headwaters in the Luquillo Forest and provide water and hydroelectric power for towns and rural areas in eastern Puerto Rico. In the past, unregulated timber cutting contributed to flooding and erosion, but today, critical watersheds—peaks, ridges, and steep slopes—are off limits to timber harvesting. As a result, the water that flows from the forest is relatively clean and free of sediment.

Wildlife Habitat

The entire forest is also a wildlife refuge. It has 68 species of native birds, many migratory birds, and numerous reptiles and amphibians. At night, the rain forest resounds with a loud chorus that may include 16 different species of frogs—the beloved coquis of Puerto Rico (fig. 14). The only native mammals are bats. However, mongooses, rats, and domestic cats have been introduced and now run wild.

Figure 14.— *The tiny Puerto Rican coqui frog (*Eleutherodactylus *spp.) courts with a musical and surprisingly loud "koki-koki" song.*

Baño de Oro Natural Area

Three-fourths of all the virgin (primary) forests that remain in Puerto Rico are located in the experimental forest. To protect this unique and valuable resource, some 2,100 acres (850 ha) have been set aside as the Baño de Oro Natural Area. Timber harvest is not allowed in this area, and no roads or trails may be built.

Important Trees

Although timber is considered to be an important use of the forest, very little has been cut in recent years. In fact, the Forest Reserve was created in response to deforestation, and emphasis has been on reforesting cutover areas. Over the years, many acres have been planted to trees. In the future, these plantations will be an important and sustainable source of timber for local use.

Luquillo Forest has 225 different species of trees and a highly diverse plant community typical of tropical rain forests around the world. Some of the most important or interesting native trees are listed here:

- **Ausubo** (*Manilkara bidentata*) is a large, slow-growing tree with a dense crown of dark-green elliptical leaves. The wood of ausubo is beautiful, resistant to termites and rot, and highly desirable for furniture and construction purposes. This was once one of the most important timber trees in Puerto Rico. Now, few large, old trees remain.
- **Fern trees** (*Cyathea arborea* and *C. aquilina*) are among the most beautiful and fascinating plants of tropical forests. These small, evergreen trees have slender trunks and feathery, lacy leaves called fronds. The Carib Indians used the hollow stems to carry and preserve fire. Now these stems are cut for use as planters for orchids and bromeliads or for potting material. Fern trees are also used in home and commercial gardens. Unfortunately, most of the fern trees harvested are stolen from along roads.
- **Palo colorado** (*Cyrilla racemiflora*) is a very large tree that may live to be 1,000 years old. Its name comes from its reddish bark, which splits off in thin plates or scales. Large, old palo colorado trees are important nest trees for the Puerto Rican parrot. Many of these trees support complete communities of other plants: vines, mosses, herbs, ferns, liverworts, and even seedlings of other tree species.
- **Tabonuco** (*Dacryodes excelsa*) is perhaps the most stately tree in "El Yunque." These forest giants often reach a height of 100 feet (30 m) and a diameter of 40 inches (1 m). The smooth, pale bark often exudes a white resin useful for starting fires and for incense. The wood of tabonuco was formerly used to make furniture and boxes, but today it is rarely cut.
- **Sierra palm** (*Prestoea montana*) is a striking feature of the Luquillo Experimental Forest. Although palms are slow growing, they reproduce in abundance in the shade on the forest floor and survive hurricanes that topple many broad-leaved forest trees. Palm fruits are produced all year and are a staple food of the Puerto Rican parrot.

International Institute of Tropical Forestry

Establishment of a forestry research station in Puerto Rico was authorized by Congress in 1927, but it was not until 1939 that the Tropical Forest Experiment Station, now called the International Institute of Tropical Forestry, was created. Located on the grounds of the Agriculture Experiment Station at the University of Puerto Rico in Río Piedras, the institute has become a focal point for forestry research and education in tropical America. The designation as the Luquillo Experimental Forest in 1956 reflected the growing importance of forestry research in the region.

Together, the International Institute of Tropical Forestry and the Caribbean National Forest have pioneered the application of sound forest management principles in tropical America. Between 1931 and 1956, the amount of land in the Luquillo Forest was increased and consolidated from surrounding farmlands, and trespass was essentially eliminated. By 1975, 10,000 acres (4,000 ha) of land had been replanted. Today, plantation forests look so much like the native forests that few people can tell them apart, and they have many of the same benefits. In 1934, as an aid to reforestation efforts, research was initiated on natural regeneration, and species trials were begun. Growth records have been kept on approximately 20,000 trees for nearly 50 years.

Researchers at the institute were the first to report decrease in the Puerto Rican parrot population in the national forest. Subsequently, a monitoring and research program was begun, and the parrot was given protection under the Endangered Species Act. Over the years, the captive flock has continued to increase, giving hope that the wild population can eventually be reestablished.

Over the years, the International Institute of Tropical Forestry has enjoyed a growing reputation in forestry extension and education. A technical journal, "The Caribbean Forester," was published between 1939 and 1963. Thousands of people have participated in training courses and technical meetings, and the library has one of the best collections of tropical forestry information in the world. In 1989, the experimental forest was designated for a long-term ecological research by the National Science Foundation. As a result, scientists are now learning more about the native flora and fauna and how they react to natural and human-caused disturbances.

Recreation facilities have been developed, including trails, picnic sites, visitor centers, and scenic overlooks. More than half a million visitors a year now enjoy the Caribbean National Forest.

New Directions

The Caribbean National Forest is a small fraction of the original forests of Puerto Rico and very small compared to the national forests of the United States, Brazil, and elsewhere. But this forest is very special. Since the 1930's, work done there helped to reverse the trend of forest destruction in Puerto Rico. The result is a living treasure—an example of how tropical forests can be protected and managed for human benefit.

Plans and programs are being developed to improve and extend the benefits from this valuable area. Efforts include: (1) refining the environmental education presentation at "El Portal del Yunque" visitor's center, (2) improve recreational opportunities in other parts of the forest, (3) acquire small pieces of property around the periphery of the forest that suffer from heavy recreational impact, (4) develop a small-scale logging demonstration using the most environmental-friendly techniques available to provide wood to local artisans, (5) assist state and nongovernment agencies with land management problems through technical assistance, (6) extend activities to promote the recovery of endangered species of plants as well as animals, and (7) promote sound urban forestry programs throughout the island.

Changes are also planned in the research program. In the past 50 years, many advances have been made, particularly in plantation forestry. Foresters now have extensive knowledge about how to reforest tropical sites. In the future, more emphasis will be placed on learning how tropical forests function—how plants and animals interact in complex ecosystems and in global ecology. Such information will help to restore damaged forests, plan forestry programs for local economies, and show how to mitigate the global effects of air and water pollution.

While research in the Caribbean will always be an important part of the institute's program, studies are also being initiated elsewhere in Latin America. Emphasis will be on forest hydrology and ecology, forest rehabilitation and management, the causes of species loss, and improvement of access to technical information.

HIGHLIGHTS IN THE HISTORY OF THE LUQUILLO EXPERIMENTAL FOREST

1839—First Spanish forest conservation law for Puerto Rico.

1876—The Spanish Crown proclaims El Yunque and other areas in Puerto Rico as forest reserves.

1903—President Roosevelt designates the Luquillo Forest Reserve (now called the Caribbean National Forest).

1905—The Bureau of Forestry, U.S. Department of Agriculture, publishes the first detailed report about the forest and its resources.

1931—The first forest plantations (mahogany) are established.

1933—The Emergency Conservation Program began. With the Civilian Conservation Corps (1937), extensive work is accomplished in reforestation, road construction, and other improvements.

1935—Name changed to the Caribbean National Forest.

1937—First timber inventory completed.

1939—Tropical Forest Experiment Station (now the International Institute of Tropical Forestry) established.

1946—Forest designated as a wildlife refuge.

1956—Entire forest designated as the Luquillo Experimental Forest in recognition of the growing importance of research.

1968—Conservation efforts began for the Puerto Rican parrot.

1976—The Luquillo Experimental Forest is designated as a Biosphere Reserve.

1988—Experiment Station receives a grant from the National Science Foundation for long-term ecological research.

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Note:
Publications may be reviewed in the library at the International Institute of Tropical Forestry, Río Piedras, PR, or are available on loan from some public libraries.

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Tropical forests, which circle the globe, are surprisingly diverse, ranging from rain forests to savannas. Tropical forests are disappearing at an alarming rate as they are converted to farmland and other uses. Modern forest management practices can help stem the tide by providing income and valuable products while maintaining forest cover. Puerto Rico has already gone through deforestation and partial reforestation. The Luquillo Experimental Forest is an interesting example of a protected and managed tropical forest.

Keywords: Deforestation, forest management, Luquillo Experimental Forest, tropical forest.