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8 PRECOLUMBIAN SILVICULTURE AND INDIGENOUS MANAGEMENT OF NEOTROPICAL FORESTS

According to most accounts, the practice of silviculture was first introduced to the tropics in the late 1800s by colonial foresters working in Asia. German foresters drew up management plans for Burmese teak as early as 1860 (U Kyaw Zan 1953), and the first tropical forestry training center was founded in 1878 in Dehra Dun, India (Lamprecht 1989). British foresters working in Peninsula Malaysia around the turn of the century developed silvicultural prescriptions to enhance the productivity of *Palaquium gutta,* an important latex-producing tree in local dipterocarp forests (Wyatt-Smith 1963), and the first textbook of tropical silviculture (Troup's three-volume *Silviculture of Indian Trees*) was published in 1922. In 1926, the regeneration improvement felling (RIF) system was formulated in Malaysia. In addition to being the first in a long line of tropical shelterwood systems, the RIF is usually considered to be the first documented and codified example of a silvicultural system for the tropics (Taylor 1962).

What is overlooked in this historical treatment of tropical silviculture is the fact that the indigenous populations of Central and South America have been using, manipulating, and managing tropical forests for several thousand years. Long before Columbus arrived in the New World, indigenous foresters were already skilled in "the art of producing and tending a forest," i.e., they were, as defined by Smith et al. (1997), practicing silviculture. In spite of the enduring myth that Neotropical forests were a vast, pristine wilderness in 1492, there is considerable evidence to suggest that the structure and composition of many forests have been

deliberately molded by anthropogenic forces (Roosevelt 1989; Balée 1989; Denevan 1992). In the same way that German foresters used selective thinning, weeding, and enrichment planting to maximize the density and growth of teak trees in Burma, Precolumbian woodsmen used their own silvicultural techniques to favor the growth of desirable forest species.

The basic problem in trying to reconstruct the forest management practices of ancient cultures is the lack of direct evidence. There are no bark-paper codices describing Mayan silviculture, or pollen records documenting the subtle manipulation of forest composition, or fossilized plant remains showing the variety and abundance of plant resources obtained from managed forests. What we are left with is simply the observation that these same cultures are skilled forest managers today and that many of the forests they inhabit exhibit conspicuous imprints of past silvicultural treatment. These two pieces of the puzzle, however, can provide convincing glimpses of what silviculture might have been like in the New World prior of Columbus.

The purpose of this article is threefold. The first and perhaps most important objective is to challenge the common assumption that the tropical forests of the New World were virgin, untouched plant communities during Precolumbian times. The second objective is to provide an overview of the variety of indigenous forest management in Central and South America, to speculate on the types of silvicultural interventions that might have been used a thousand years ago, and to present examples of tropical trees and forests that seem to have been produced through the conscious activities of Precolumbian silviculturists. The final objective is to highlight the potential of indigenous silviculture in the search for more sustainable ways of using tropical forests. By necessity, these management systems are parsimonious, low input, and very effective. They are the culmination of hundreds of years of trial and error, and there is a lot to be learned from them.

INDIGENOUS FOREST MANAGEMENT IN THE NEOTROPICS

In contrast to more conventional forms of forest exploitation in the tropics, indigenous systems of silviculture can be very hard to detect. There are no marked stumps, no bulldozer roads, and no skid trails, and no straight lines of neatly planted seedlings. If non-timber resources are the product of interest, there may, in fact, be no visible evidence that forest management is occurring on the site. To the untrained eye, the managed and the pristine can easily merge into one.

Given the relative invisibility of these practices, it is not surprising that the subtle manipulation of forest vegetation by indigenous communities went unnoticed for so many years. The early studies that did focus on forest use were usually more concerned with the slashing and burning of small agricultural plots than with what happened after the plots were "abandoned." Much of this work took a rather dim view of forest farming (e.g., FAO 1957; Webb 1960; Watters 1971). Once researchers began to take a closer look at the swidden plots created by traditional communities, however, they found a surprisingly complex and diverse mixture of annual and perennial crops. Far

from being the result of "an inefficient and destructive form of land-use" (FAO 1957), local agroforestry systems were found to produce a multitude of useful plant resources, to protect and enrich the soil, to provide important wildlife habitat, and to accelerate the recovery of forest vegetation on the site (Carneiro 1961; Harris 1971; Hecht 1982). With further investigation, it was discovered that local communities actively manage fallow regrowth following shifting cultivation, enriching it with useful species and consciously directing the course of forest succession on the site (Alcorn 1984a; Denevan et al. 1984; Posey 1982). Finally, several studies have shown that indigenous populations also use silvicultural techniques to control the composition and structure of intact forests (Gordon 1982; Alcorn 1983; Gómez-Pompa et al. 1987).

What is clear from all of these studies is that indigenous populations in the Neotropics have evolved a diverse array of techniques for managing trees and forests. For the purposes of this essay, we can group all of these techniques into three main silvicultural systems based on the successional status of the vegetation being managed and the nature and intensity of the interventions employed: (1) homegarden systems, (2) managed fallow systems, and (3) managed forest systems. Homegardens and managed forests are essentially polycyclic systems (sensu Dawkins 1958) in which only a small fraction of the growing stock is removed in each harvest. Canopy cover is continuous, and the forest contains a wide range of different age classes. Managed fallow systems, on the other hand, can be either monocyclic or polycyclic, depending on whether the fallow is ultimately cleared and cycled back into agriculture or maintained in forest and gradually transformed into a managed forest. The actual intensity of management usually increases from managed forest to fallow to homegarden. Each of these systems is discussed in detail below.

HOMEGARDENS

Homegardens, also known as dooryard gardens or kitchen gardens, are diverse, multistoried mixtures of trees, shrubs, vines, and herbaceous plants maintained as an annex to the house (figure 8.1). In addition to edible fruits and other food crops, homegardens are a repository of medicinal plants, spices, ornamentals, and other utilitarian species frequently used by the household. Because of their proximity and easy access, homegardens are highly managed. Family members spend spare time here tending their plants, and children learn to identify and care for useful species by observing the actions of their parents.

The structure and composition of a Neotropical homegarden is highly variable and reflects the cultural background, needs, motivation, and horticultural proficiency of the household that has created it. There is no characteristic or standard homegarden. Riberēnos (floodplain farmers) in the Peruvian Amazon manage 168 plant species in their homegardens, yet none of these species is present in all of the gardens and more than half (90 species) are found in only one or two gardens (Padoch and de Jong 1991). Similar patterns of heterogeneity were noted by Alcorn (1984b), who recorded 182 plant species in the gardens of Huastec Maya in Mexico. The Costa Rican homegar-

FIGURE 8.1. Maya homegarden in Quintana Roo, Mexico. Large, buttressed trees are *Brosimum alicastrum*.

dens studied by Price (1983), on the other hand, contained an average of only 16 species of plants.

The origin of the plant material managed in homegardens is also variable, and local households blend together dynamic mixtures of wild plants, semidomesticates, and domesticated stock. Novel species and recently introduced domesticates appear to be especially prized. Studies of Maya homegardens in Yucatán reveal that 26 percent of the species are nonnatives introduced to the region after the sixteenth century (Barrera 1980). The remaining species are either native to the local flora (61 percent) or Neotropical elements not found locally in the wild (13 percent). Similarly, one-third of the species found in Choco gardens in Panama are introduced domesticates (Covich and Nickerson 1966), and the Ka'apor of Brazil include 36 introduced species in their homegardens (Balée 1994). Twenty-five of the nonnative domesticates managed by the Ka'apor are of Old World origin (e.g., *Citrus* spp., *Mangifera indica*, *Coffea arabica*, and *Colocasia esculenta*). Apparently, the first trials of exotic germ plasm are usually conducted in homegardens where the owner can keep a close eye on things.

The creation and maintenance of homegardens involve several silvicultural operations. Perhaps the most fundamental of these is periodic weeding or brushing, which keeps the garden open, reduces the competition from secondary vegetation, and provides easy access to certain plants. The selection of which plants or genotypes to keep and which to remove is made spontaneously during the weeding process. Although some form of weeding is usually employed in all homegarden systems, the importance

of this management operation varies from place to place. The Ka'apor, for example, refer to their homegardens as *kar,* which means an area that has been intensively weeded (Balée 1994), while some Huastec Maya families create gardens with large areas of secondary vegetation that are weeded and cleaned only at irregular intervals (Alcorn 1984a). These thickets, which appear wild to the untrained eye, contain a large concentration of medicinal species, food items, and ritual and utilitarian plants. Padoch and de Jong (1991) found neatly weeded gardens adjacent to gardens that were totally overgrown with weeds in the same Peruvian village.

Planting is also an important activity in the management of homegardens. The intensity of this operation ranges from casual dispersal of seeds into the garden and subsequent protection of the seedling to careful sowing and tending of certain species in nurseries for later transplanting. The Choco produce seedlings for their homegardens in old cans and dishes placed on stumps so that they won't be trampled by livestock or children (Covich and Nickerson 1966). The seedlings are transplanted into the garden when they are of sufficient size to survive the disturbance. Maya foresters in Yucatán construct elevated, compost-filled seedbeds known as *ka'anché* for germinating and growing planting stock (Vargas 1983). The Ka'apor, who employ a less labor intensive strategy at times, report that several of the tree species in their homegardens (e.g., *Theobroma grandiflorum* and *T. speciosum*) are planted by first "swallowing the seed" (Balée 1994). Simple planting and weeding, at whatever intensity, are the core operations that shape the floristic composition of a homegarden. Desirable species are introduced by planting cuttings, seeds, or seedlings or by selectively sparing the volunteers that recruit themselves into the garden. Undesirable stems are removed through periodic weeding.

Most homegardens are fertilized by a continual input of household refuse, organic material from periodic weedings, and ashes from kitchen fires. In communities with livestock, manure may also be added. Whether by conscious purpose or unintended consequence, the addition of this organic waste and compost enriches the soil and enhances the long-term productivity of the garden. Given the low nutrient status of many tropical soils and the low light levels, the high herbivory, and the intense competition for resources in the understory of a tropical forest, homegardens provide a growth environment that is far superior to that confronted by wild species.

A final aspect of homegardens relevant to the present discussion concerns what happens to them after the owners move. Most homegardens are quickly swamped by fast-growing, secondary vegetation once the house is abandoned. The herbaceous cultivars and the nonnative domesticates are the first plants to succumb to this onslaught. The larger trees, with their crowns above the successional fracas and their roots below it, exhibit the highest survivorship and continue to grow and reproduce. In cases where the owners of the garden return periodically to the site to harvest, these trees may be lightly weeded and the competing brush cut back to provide better access. With time, the surviving relicts of the homegarden become engulfed by the developing forest. These trees must be able to establish seedlings under forest conditions for there to be a second or third generation of homegarden progeny. It is at this point that many of the introduced and domesticated tree species are lost. They may continue to flower and

produce fruit, but their seedlings are ineffective in securing a permanent place in the forest. The native tree species, especially those obtained from local forests, are a different story. These species were able to maintain themselves in the forest before the homegarden was created, and they continue to do so in the absence of human intervention. The salient difference is that now the trees are growing in an exceptionally fertile microsite at atypically high densities, and now the original seed dispersers and pollinators have returned because there are fewer people in the forest. The net result is that distribution and abundance of many of the founder populations created in homegardens may actually increase over time. This general pattern has been observed for *Spondias mombin* (Balée 1994), *Brosimum alicastrum* (Peters 1989), *Couma macrocarpa* (Gordon 1982), *Astrocaryum vulgare* (Wessels-Boer 1965), and a variety of other useful forest species in the Neotropics (Balée 1989; Gómez-Pompa and Kaus 1990).

MANAGED FALLOWS

Fallows are tracts of forest that are being left to recover after several years of cultivation. In contrast to homegardens, which temporarily arrest succession, managed fallow systems are designed to facilitate and enrich the successional process. The spontaneous growth of secondary vegetation is viewed as a welcome consequence of farming, not as a weed problem (Alcorn 1981). Through subtle substitutions in the species assemblage of the developing vegetation and gradual manipulations of forest structure, managed fallow systems can produce lasting, if almost imperceptible changes, in the forest.

Monocyclic fallows are the most common variant of this system in the Neotropics. As it is generally practiced, small plots of forest are felled and burned and the clearing is planted with agricultural crops such as corn or manioc. Other useful species, both domesticates and semidomesticates, are also introduced at this time. After one or two years of crop production, the site fills with young secondary growth that has been enriched with fruit trees, construction materials, and medicinal plants. In short fallow systems, such as employed by the Huastec Maya, the managed successional sere is allowed to develop for 4 to 8 years before it is cleared to start another agricultural cycle (Alcorn 1984). The Totonac of Veracruz, Mexico, fallow their fields for a slightly longer period (10 to 12 years) to extend the productive life of the vanilla vines planted on the site (Kelly and Palerm 1952). Many indigenous communities in South America manage their fallows using long-rotation systems. For example, the Bora of northeastern Peru (Denevan et al. 1984), the Runa of Ecuador (Irvine 1989), and the Kayapó of central Brazil (Posey 1984) all maintain enriched forest regrowth for 20 years or more before clearing it to replant. The ribereños of Tamshiyacu, Peru, mold their fallows into high-density stands of umarí (*Poraqueiba sericea*) and Brazil nut (*Bertholletia excelsa*), both of which are valuable market fruits, and they may leave these trees standing for 25 to 50 years (Padoch et al. 1985).

Polycyclic fallow systems start out the same way as monocyclic systems, but the fallow is allowed to continue growing until mature forest is produced. Fruits and fibers and medicinal plants are periodically harvested as the forest develops, but there is never

a final harvest cut or felling to clear the plot as with monocyclic systems. Over time, polycyclic managed fallows become managed forest orchards. For example, many of the te'lom and pet kotoob managed forests in Mexico (described below) were once polycyclic managed fallows.

The creation of a managed fallow starts during the early phases of the agricultural cycle when the forest is cleared. Some useful tree species are usually spared during the clearing operation to insure their presence in the fallow. The Bora, for example, refrain from cutting valuable timber species and certain palms (Denevan et al. 1984); the Yucatec Maya will spare a tree because of its fruits, fibers, medicinal properties, or nitrogen-fixing ability (Gómez-Pompa and Kaus 1990). Other subtle management techniques such as directional felling, coppicing, and slash piling are also used during the clearing process. The felled trees and slash are allowed to dry for several weeks and then burned to prepare the site for planting.

The primary agricultural crop is planted a week or so after burning. A variety of domesticated and semidomesticated tree species may also be introduced at this time. Edible fruit trees such as uvilla (*Pourouma cecropiaefolia*), peach palm (*Bactris gasipaes*), pacae (*Inga* spp.), and cashew (*Anacardium occidentale*) are common components of young swiddens in Amazonia (figure 8.2). These fast-growing, heliophilic trees are usually aggregated in the plot, either in the center to facilitate access or along the

FIGURE 8.2. Young managed fallow near village of Tamshiyacu in Peruvian Amazonia. A few cassava (*Manihot esculenta*) plants share the site with pineapples, bananas, and peach palms (*Bactris gasipaes*). Large leaves in the foreground are young umarí (*Poraqueiba sericea*) plants. (Photo by C. Padoch.)

perimeter so that they don't interfere with the primary crops. The young plot is periodically weeded to slow the growth of secondary vegetation, and some farmers fertilize their plants by adding ashes from household cooking fires or by mounding and burning the stubble left after harvesting. Although the frequency of weeding and fertilization appears to decrease once the annual cropping phase has finished, additional species continue to be added to the plot by planting, transplanting, or selectively favoring the growth of certain secondary species. Species introduced after the cropping phase are usually long-lived, shade-tolerant nondomesticates that are able to survive the highly competitive conditions in the understory of the developing fallow. Common examples include hogplum (*Spondias mombin*), Brazil nut (*Bertholletia excelsa*), and wild cacao (*Theobroma speciosum*).

After five or six years, the fallow contains a mixture of successional vegetation and harvestable tree species of either planted or spontaneous origin. These managed plots can be very diverse. Of the 645 plants collected in young fallows created by the Bora, 207 plants from 188 species were identified as useful (Unruh and Alcorn 1988). Other farmers, like the ribereños in Peru who plant Brazil nuts (Padoch et al. 1985) or the Kalapalo of central Brazil who manage for *Caryocar brasilensis* (Basso 1974), opt to create high-density stands of only one or two species in their fallows.

Silvicultural operations shift from intensive planting and tending to periodic harvesting and occasional slash weeding as the fallows increase in age. Local farmers return to their fallows during fruiting season to harvest, and they may slash the weeds around the base of the tree to aid in the collection of fruits. Animals are also attracted to these sites because of the fruit trees and hunting is another incentive to visit and casually manage older fallows. Depending on local traditions and priorities, one of three things can happen to an old fallow. In many cases, it will be felled and burned to start the agricultural cycle again (i.e., monocyclic systems). Alternatively, a decision will be made to continue managing the woody vegetation on the site, and it will be gradually converted to a managed forest or orchard (i.e., polycyclic systems). Finally, the old fallow will simply be abandoned when the village picks up and moves to another locale. It should be noted that villagers may return to these old sites for many years to hunt, to camp, and to harvest fruits.

Managed fallows produce long-term changes in the floristic composition of the forest. After several cycles of clearing, burning, and farming, the mix of species in the fallow regrowth becomes progressively simplified. Successional vegetation continues to swamp the site after clearing and must be weeded, but the overall species richness of the vegetation gradually declines. Several factors are responsible for this subtle biotic impoverishment. Repeated burning destroys many of the buried seeds in the soil (Ewel et al. 1981), and selective weeding reduces the density of many nonuseful taxa. The dispersal of large-seeded forest species is diminished because of lack of seed trees, lack of dispersal agents, or lack of appropriate regeneration niches. Over time, the net effect is that the overall species diversity of the fallow declines while the relative contribution of harvestable, useful trees increases. These floristic changes have only a minimal impact on the recovery and function of the tropical forest ecosystem (Uhl and Jordan

1984; Uhl et al. 1990), and they are exactly the result that a successful silvicultural system should produce, i.e., increase the density of desirable species by decreasing the density of undesirable ones. As was noted previously for homegardens, managed fallow systems produce small plots of forest enriched with useful species. Many of these species are native forest trees, and some of them will be able to maintain their local dominance on the old fallow site indefinitely.

MANAGED FORESTS

Managed forest systems are the most overlooked and least studied form of indigenous plant management. Unlike homegardens or managed fallows, which are highly visible and spatially defined, managed forests get lost in what is usually considered natural or primary forest. In most cases, the only evidence that some form of management is taking place is the distribution and abundance of useful trees in the forest.

Managed forests can be produced from old fallows, young fallows, homegardens, or intact forest. In each case, silvicultural treatment removes the unwanted stems through weeding and selective felling and introduces new stems through enrichment planting, coppicing, and protection of desirable volunteer species. Fertilization, pruning, and mulching are employed in some systems to enhance the productivity of important market species. Ecologically, managed forest systems represent the endpoint of the successional process on a site. Most of the favored species are shade-tolerant canopy trees adapted for growth and regeneration under a closed canopy or in small canopy gaps. Selective felling and the occasional windthrow provide the canopy openings required to maintain these species. Pioneer species that colonize the larger canopy gaps will be tolerated or removed. Rarely, however, will managed forests be cleared or the canopy drastically opened to initiate secondary succession and do something else with the site.

The Huastec Maya of Mexico create complex managed forests known as te'lom, or "the place of trees" (Alcorn 1984a,b). These forests, which are usually developed from old fallows, are most commonly found on slopes and ridges, where they control erosion and protect the watershed, or along streams, where they provide a shady riparian environment. Alcorn (1983) estimates that about 25 percent of community land is maintained in managed forest. Silvicultural practices in these forests are limited to casual weeding, enrichment planting, occasional selective felling of unproductive fruit trees, and protection of desirable wild or volunteer species. Desirable species that do not recruit themselves into the te'lom, or do so in the wrong place, will be transplanted from the forest or a homegarden. Undesirable plants will be removed by weeding or felling. After several years of irregular weeding and planting, the floristic composition of the forest becomes enriched with useful species. Different parts of the forest are managed for different groups of resources with the result that a te'lom is composed of several distinct stands. A managed forest, for example, may contain a small stand of trees useful for construction, a parcel of avocado trees, a stand of copal trees (*Protium*
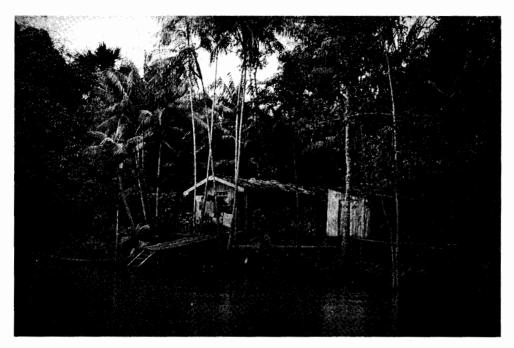
copal), a commercial coffee grove, and a patch of firewood trees. The species composition, size, and location of each stand varies from site to site and reflects the management objectives of the individual farmer.

Floristic inventories have shown that te'lom may contain more than 300 plant species (Alcorn 1983). In addition to edible fruits, construction materials, medicinal plants, and firewood, plants used for cordage, fish poison, tool handles, dyes, soap, incense, and tanning are also produced in Huateca managed forests. There are 81 food plants in these forests, including important Old World domesticates such as mangos, oranges, and coffee. Coffee and the native ornamental palm *Chamaedorea elegans* are common commercial products.

A similar type of managed forest called pet kot was constructed by the Yucatec Maya. The system takes its name from the low wall of stones (*pet,* circular; *kot,* wall of loose stones) that characteristically surrounds the forest plot (Barrera-Vázquez 1980). These enriched patches of tall forest stand out in stark contrast to the surrounding low deciduous forest, which is the dominant vegetation in the area. Pet kot are created from either old fallows or natural forest through the continual enrichment of the site with desirable species. The introduced species may come from local forests, from more distant and humid forests of the Maya realm, or from homegardens. Common tree genera found in pet kot include *Brosimum, Spondias, Pithecellobium, Malmea, Bursera,* and *Sabal,* which also occur as dominant elements in homegardens of the region (C. E. Smith and Cameron 1977). The creation of pet kot near areas of shifting cultivation would have provided local farmers with a shady, resource-rich place to stay while they were tending their fields. Most of the weeding, thinning, and planting operations required to maintain the pet kot undoubtedly took place during these visits.

Although the local Maya no longer make pet kot, other types of enriched forest orchards are created on the slopes and bottom of sinkholes (cenotes) and in scattered patches of deep soil (rejoyas) in karst areas (Gómez-Pompa 1987). These managed forests are of particular interest because of their small size, careful placement in especially moist and fertile microsites, and high density of native and introduced fruit species (e.g., *Citrus, Persea, Musa, Manilkara,* and *Annona*). The blending of water, fertile soils, fruit trees, and forests in a droughty, karst environment reflects a considerable degree of silvicultural acumen.

Ribereño farmers in the Amazon estuary of Brazil actively manage floodplain forests to favor the density and productivity of several economically important forest resources (e.g., *Euterpe oleracea, Mauritia flexuosa,* and *Theobroma cacao;* figure 8.3). Management involves a number of operations designed to enrich the forest and enhance fruit production (Anderson et al. 1985). Enrichment occurs through selective weeding and thinning of competitors as well as through planting and protection of desirable volunteers. Cacao, mango, genipap (*Genipa americana*), and cupuaçu (*Theobroma grandiflorum*) are frequently planted, while *Spondias mombin, Hevea brasiliensis,* and *Virola surinamensis,* a valuable timber species, are desirable and carefully protected volunteers. Woody vines, the spiny murumuru palm (*Astrocaryum murumuru*), and firewood trees are usually the first victims of selective thinning. Large trees are

FIGURE 8.3. Managed floodplain forest dominated by açaí palms (*Euterpe oleracea*) on Ilha das Onças in the Amazon estuary.

frequently girdled rather than felled to minimize damage to the surrounding trees. Fertilizing and thinning techniques are used to enhance the productivity of commercial species. For example, the decaying leaves and inflorescences of the *Euterpe* palm are used as mulch and piled at the base of reproductive trees. Local residents also selectively thin the multiple stems of the *Euterpe* palm when harvesting palm hearts, and this practice, when judiciously applied, enhances the overall production of fruits on the remaining stems (Anderson 1990).

There are numerous varieties of managed forest systems in the Amazon estuary, yet each one appears to be successful in enhancing the forest resources of interest. Compared to unmanaged floodplain forests, managed forests have a more open canopy, fewer total stems, a lower species richness, and a greater density of useful stems (Anderson et al. 1995). The exact species mix favored by the farmer seems to depend on the age of the forest, the flooding regime, and the distance to market. In each case, however, the structure and composition of the forest is notably altered

Managed forest systems are subtle, but they can produce lasting changes. Certain trees and species are selectively removed, and the longer that management continues, the less frequently these unwanted volunteers will crop up in the forest. Over time, as seed trees and soil seed banks are depleted, these directional floristic changes can become persistent. As long as the communities that initially shaped the forest are present, the te'lom, pet kot, or managed floodplain forest will be maintained and continually refined, because of its cultural, ecological, and economic value. If the site is abandoned,

many of the abundant canopy species in the managed forest will probably maintain themselves. This persistence is the result of long-term silvicultural treatment. Through selective weeding and thinning, the regeneration of desirable canopy species is favored over less useful taxa. After several decades of this treatment, the canopy species develop all-age populations with seedlings, saplings, juveniles, poles, and adults. In the absence of human intervention, these canopy species will continue growing on the site for several generations even if the level of regeneration is drastically reduced. If the site is abandoned and then later cleared for agriculture by another cultural group, a successional process will be initiated, and a whole different suite of species may occupy the site. In all probability, however, the second community to farm the site possesses its own form of traditional silviculture and will, like its predecessors, spare many of the valuable canopy trees when the forest is cleared. Although the old forest temporarily will be lost, many of the genotypes produced by the previous management system will play a major role in shaping the new forest that develops on the site.

IMPRINTS OF PRECOLUMBIAN SILVICULTURE

In spite of the number of indigenous management systems that are practiced today in the Neotropics, it would be erroneous to assume that these same systems were applied in the same way and at the same intensity during Precolumbian times. Forest management systems evolve based on the needs, available resources, and cultural traditions of a particular group of people at a given point in time. Clearly, life in the New World prior to European contact was quite a bit different from today's. For one thing, the native population in the Americas was several orders of magnitude higher then (Borah 1970; Meggers 1971; Parsons 1975). Denevan (1992) estimates that there were more than 50 million native people during Precolumbian times, with 17 million in Mexico, 6 million in Central America, and almost 9 million in lowland Amazonia. Within 100 years following the arrival of the Europeans, 90 percent of that population was lost to disease, enslaved, or killed (Cook and Borah 1971). A wealth of silvicultural experience was also lost at this time.

The social organization of indigenous communities was much different during Precolumbian times. Many of the populations were concentrated in large settlements containing thousands of people with complex economies based on intensive use of resources and extensive trade networks (Turner 1976; Roosevelt 1989). Chiefdoms extending over tens of thousands of hectares were established, and elaborate earthworks were constructed for permanent cultivation, water control, defense, habitation, and burial (Roosevelt 1987). In contrast, the indigenous populations of today live in small, independent communities and largely practice a subsistence level of agriculture and forest resource exploitation. Given their population density, sociopolitical organization, and intensity of resource use, Precolumbian indigenous communities would have had a significantly larger impact on the forest than their present-day descendants. They probably applied many of the same silvicultural systems, e.g., homegardens, managed fallows, and managed forests, but they would have done so over larger areas of

forest, for longer periods of time, at a much higher intensity. It is really not surprising that hundreds of years of indigenous management have left a permanent imprint on the forests of the Neotropics.

ENRICHMENT OF USEFUL SPECIES

The most noticeable residual effects of Precolumbian forest management are the high-density aggregations of useful species found in many Neotropical forests. These floristic anomalies have been found in the vicinity of human settlements in numerous areas of "primary" forest. The nomadic Guajá in eastern Amazonia always seem to locate their temporary villages near dense stands of the babassu palm (*Attalea speciosa*) that are surrounded by species-rich forest. The edible seeds and fleshy pulp of the palm play an important role in the diet of the Guajá. Excavations in some of these villages yielded potsherds and ceramic manioc griddles of the neighboring Ka'apor whose ancestors used to live on the site (Balée 1987). Other old Ka'apor sites also contain dense enclaves of babassu. The Ka'apor are skilled forest managers (Balée 1994), and the scattered populations of babassu within the forest are thought to be relics from their old managed fallows. Babassu seedlings can easily dominate burned forest clearings because of their cryptogeal germination, i.e., the apical meristem initially buries itself in the ground, rather than growing up, so that is protected from fire, and adult palms were probably spared during the clearing process. Over the past several hundred years, the Ka'apor have created permanent, two- to three-hectare stands of babassu palms in many of the forests of northern Maranhão and eastern Pará. Although their relations with the Guajá have historically been rather hostile, the vestiges of their silvicultural practice have been a lasting gift to this tribe.

Several other useful Amazonian palm species occur in dense aggregations in areas of previous human occupation. *Astrocaryum vulgare,* for example, forms high-density stands in old secondary forests in eastern Amazonia (Balée and Gély 1989), and the species is also common on archaeological sites in coastal Pará. Wessels-Boer (1965) reports that *A. vulgare* never occurs in undisturbed forests in Suriname. The palm is used locally as a source of fiber. Enriched pockets of *Elaeis oleifera,* a native oil palm, and *Acrocomia aculeata,* a source of edible fruits, also have been reported from old settlement sites along the lower Amazon.

Clumps of fruit trees are another important indicator of indigenous management in Amazonian forests. *Grias peruviana* is a common edible fruit in the seasonally flooded forest of Peruvian Amazonia. The species is planted in homegardens and is occasionally managed in fallows by present-day ribereños (Peters et al. 1989). The species aggressively maintains itself on these sites after abandonment and has been observed to form populations of 400–500 adult trees/ha along the lower Ucayali River in Peru (Peters unpublished data). Groves of *Platonia insignis* trees, an important native fruit for the Ka'apor, have been reported from old settlement sites in the Ka'apor reserve in Maranhão (Balée 1989), and Basso (1974) found populations of *Caryocar brasiliensis* "extending for several miles" around old Kalapalo villages in central Brazil. The fruits of
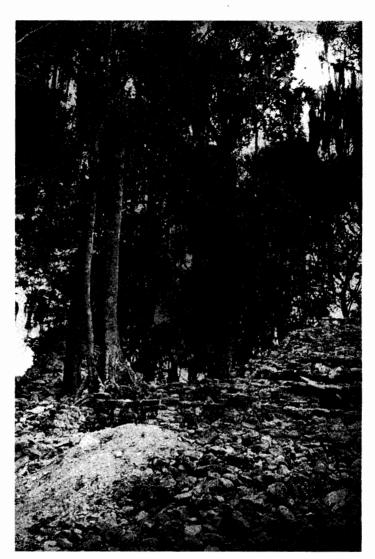
this species contain an oily pulp and a seed that is used for food. Taken together, dense clusters of fruit trees, monospecific palm stands, and other types of anthropogenic forests are estimated to comprise over 11 percent of Brazilian Amazonia (Balée 1989).

Gordon (1982) makes note of several anomalous distributions of tree species in the Bocas del Toro region of Panama. In addition to isolated groves of trees at abandoned habitation sites, which he terms "archaeological disclimaxes," plantings along the edges of trails that penetrate remote areas of forest have produced notable patterns of species enrichment. The fruit trees *Couma macropcarpa* and *Manilkara bidentata* and *Pseudolmedia spuria,* a source of edible fruits and bark cloth, occur in especially high densities in the forest. *Brosimum alicastrum* and *Dipteryx panamensis* are important trees in local arboriculture, and mixed groves of these species are frequently encountered on old Térreba settlements.

The Olmec and Maya civilizations occupied tropical forest habitats in southeastern Mexico and northern Central America for a combined period of over 3,000 years and reached population densities of 400–500 people/km^2 in some areas (Turner 1976). The forests of this region have been exploited and managed so intensively and for so long that it is very difficult to find plant communities that have not been shaped by Precolumbian foresters. Two of the most widespread forest trees in the region, *Manilkara zapota* and *Brosimum alicastrum,* were important food and construction materials for the ancient Maya. The fact that dense aggregations of both species have been reported growing on ruin sites is particularly suggestive of an anthropogenic origin for these populations (figure 8.4; Thompson 1930; Bartlett 1935; Lundell 1937). Other important forest resources in Maya subsistence, such as *Protium copal* (incense), *Ceiba pentandra* (sacred, fiber), *Dialium guianense* (edible fruit), *Haematoxylon campechianum* (dye), and *Swietenia macrophylla* (construction), are also dominant elements of the local flora. The recent discovery of relict cacao groves in karst sinkholes in northern Yucatán (Gómez-Pompa et al. 1990) provides further evidence of the intensity and sophistication with which the Maya managed their forests. Agronomically, it should not be possible to grow *Theobroma cacao* in a region with a six-month dry season (Purseglove 1968).

SELECTION OF FAVORABLE GENOTYPES

The management of plant populations involves the manipulation of the number and distribution of individuals. Some individuals are selectively favored or planted, and their numbers increase. Other individuals are removed through weeding, felling, or thinning, and their populations decrease. This change in the relative abundance of different species is the criterion by which we judge the success of existing management systems. This is also how we usually try to document the lasting impact of indigenous silviculture. Populations of forest trees, however, are notably intractable entities. High-density populations created by conscientious management may not necessarily stay high-density populations. Conversely, it is possible that low-density, managed popula-

FIGURE 8.4. *Brosimum alicastrum* trees growing on the ruins of Cobá in Quintana Roo, Mexico.

tions may convert themselves into high-density aggregations after abandonment in response to other ecological factors completely unrelated to management. All of these factors confound the study of Precolumbian silviculture. Fortunately, there are additional aspects of forest management that engender more permanent changes than the density of a particular species in the forest. When farmers are selecting individuals to favor, they are also selecting certain genotypes. After several cycles of cutting and planting, a considerable degree of artificial selection can occur in managed forests. From this perspective, the imprint of management can come into sharp focus, because the genotypes produced by forest farmers are markedly different from those produced by natural selection.

A useful example of this approach is provided by the case of *Brosimum alicastrum* in Mexico. This multipurpose species (Peters and Pardo-Tejeda 1982) is cultivated in Maya homegardens and forms high-density forest populations in many parts of Mexico (Rzedowski 1963; Gómez-Pompa 1973). The occurrence of dense aggregations of *B. alicastrum* on or near Maya ruin complexes was initially interpreted as evidence of Maya silviculture, i.e., the stands were relicts of ancient Maya orchards (Puleston 1968, 1982; Folan et al. 1979). Later work, however, suggested that the spatial relationship between *B. alicastrum* and Maya ruins was primarily the result of normal ecological processes (Miksicek et al. 1981; Lambert and Arnason 1982). As explained by Peters (1983), *B. alicastrum* forms high-density aggregations around Maya ruins because large quantities of the fruit are eaten and dispersed by the *Artibeus* bats that roost there. The bats fly to the forest, collect the fruit, bring it back to their roost, eat the fruit, and then discard the undamaged seed. The continual input of bat-dispersed seed has maintained the clumps of *B. alicastrum* around ruins for hundreds of years.

This observation, of course, does not negate the possibility that the species was used and managed by the Classic Maya. In fact, if we examine the behavior, rather than the density or spatial location, of these populations, we are presented with strong evidence of deliberate genetic improvement. This is especially notable in the phenology, productivity, and breeding systems of the *B. alicastrum* trees that cluster around the ruins at Tikal in Guatemala. For example, phenological data from various parts of its distribution indicate that fruit production by *B. alicastrum* is usually annual, with peak seedfall occurring at the onset of the rainy season (Pennington and Sarukhán 1968; Croat 1978; Peters and Pardo-Tejeda 1982). In contrast, several authors have reported that the trees at Tikal bear fruit twice a year (Gonzales 1939; Puleston 1968), while others have suggested that fruiting is continuous throughout the year with three periods of peak abundance (Coelho et al. 1976; Schlichte 1978).

Quantitative data on fruit production by *B. alicastrum* are very scarce. Using estimates from Puleston (1968) and Coelho et al. (1976), an average annual production of approximately 110 kg/tree can be calculated for the populations at Tikal (see Peters 1983). Data from a detailed ecological study of the species in Veracruz, Mexico (Peters 1989), under environmental conditions almost identical to that of Tikal (i.e., similar elevation, mean temperature and precipitation, and substrate) reveal that the maximum annual production of fruits by a large tree in this region is only 65 kg, or approximately half of that derived for the Tikal trees.

The original description of *B. alicastrum* (Swartz 1797) reports that male and female flowers are found on separate trees, i.e., the species is dioecious, and more recent taxonomic treatments have confirmed this (Berg 1972). Reports from the Tikal region (Standley and Steyermark 1946; Puleston 1968), however, have consistently described the tree as monoecious, with male and female flowers on the same tree. The salient difference between these two breeding systems is that every individual in a monoecious population can potentially produce fruit, while fruit production is limited to female trees in dioecious populations.

What we seem to be presented with in Tikal, therefore, is a dense population of *B.*

alicastrum in which fruit is produced in extremely large quantities at frequent intervals by every mature individual. The curious thing is that similar forests of the tree in other regions do not exhibit this behavior. One possible explanation is that the regeneration of the species is severely limited for some reason at Tikal, and such an abundant reproductive output is necessary to maintain the population. A second interpretation, however, is that such a high level of fruit production is in excess of what is actually required, and the atypical reproductive behavior of the *B. alicastrum* trees at Tikal are manifes- · tations of relict genotypes deliberately selected for by the continued use and management of the species. What appears to be suggested is the conscious mixing of diverse genotypes with the objective of producing an abundant, year-round supply of seeds.

THE POTENTIAL OF INDIGENOUS FOREST MANAGEMENT

Indigenous people throughout the Neotropics have developed sophisticated systems for managing forest resources. These systems produce timber and nontimber resources; they preserve valuable sources of domesticated, semidomesticated, and wild germ plasm, and they do so without irreparably destroying the forest matrix within which they are created. Every new homegarden, managed fallow, and managed forest is one more replication in a long-term experiment of silvicultural treatment that spans hundreds of years, hundred of sites, and hundreds of species. The basic understanding of the regeneration, growth, treatment, yield, and use of tropical trees that has accumulated in this vast and on-going experiment eclipses anything that European foresters have learned during their hundred years in tropical forests. The management protocols of indigenous silviculture are based on oral traditions rather than textbooks, access is by trail rather than roads, and weeds are removed selectively by hand rather than en masse by herbicide. These systems are a living, evolving embodiment of Occam's razor: never opt for something complicated when something simple will produce the same result.

Current rates of deforestation in the Neotropics have made people very aware of the difference between good forest management and bad forest management. In most people's mind, clearing thousands of hectares of Amazonian forest to put in a cattle pasture would profile as bad forest management. Selectively high-grading a stand of *Virola surinamensis* for timber with little regard for the regeneration of the species would also qualify as bad forest management. Managing hundreds of plant species in old fallows or stocking small tracts of forest with 300 species of fruits, medicinal plants, and timber trees would seem, from most perspectives, to be good forest management. If we really want to manage the forests of the Neotropics on a sustainable, long-term basis, it would seem that the study of indigenous management systems merits a much higher priority than it is currently afforded. Clearly, the easiest and quickest way to learn how to manage a tropical forest is to ask the people who have been doing it for the longest time.

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