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ECOLOGICAL BASIS FOR SUSTAINABLE DEVELOPMENT IN TROPICAL FORESTS

Gary S. Hartshorn
World Wildlife Fund, 1250 24th Street NW, Washington, DC 20037

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ABSTRACT

Unless sustainable development becomes much more prevalent in tropical forests, appreciable areas of unprotected tropical forests will not survive far into the twenty-first century. Sustainable tropical forestry must integrate forest conservation and economic development. Key ecological factors discussed here include: reproduction, natural regeneration, growth, ecosystem functions, and biodiversity conservation. Four models of sustainable tropical forestry are described: 1) Industrial timber production based on the PORTICO company in Costa Rica that owns and manages its production forests and makes a substantive investment in research. 2) Community-based timber production using the Yánesha Forestry Cooperative in the Peruvian Amazon as an example of local empowerment over the protection and use of forests. This Coop has a local processing facility that enables most of the timber to be marketed, and it uses an innovative strip-cut management system that promotes excellent natural regeneration of native tree species. 3) Community-based production of nontimber forest products depends on local rights of access or tenure to tropical forests. However, more information is needed on harvestable levels and management techniques as local preferences move from subsistence uses to commercial production. 4) Locally controlled nature tourism is touted as the most benign use of tropical forests, but local communities receive minimal economic returns and have little say in prioritizing development objectives.

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INTRODUCTION

Sustainable development in tropical forests is a high profile, often contentious global issue. National and local owners of tropical forests believe it is their prerogative—indeed right—to use their forest resources to meet development objectives. Environmentalists argue that tropical forests are unique global resources that should be protected from any or all development activities. The development–protection dichotomy reaches extremes with regard to tropical forests, involving issues such as species protection, concessionary policy, multinational involvement, indigenous peoples, local access and/or tenure, timber vs. nontimber forest products, and sustainable development, inter alia. Sustainable tropical forestry based on natural forests has the potential to conserve far more biodiversity than does plantation forestry.

In the context of tropical forests, the phrases "sustainable development" and "sustainability" have generated much discussion (18, 28, 41, 59, 88, 96). Books are devoted to sustainable forestry (5, 108). Critics point out that, in the case of forests, sustainability of development cannot be proven until the second or third rotation. This may be a valid criticism, but it ignores the importance of process, i.e. working toward more sustainable forestry.

Unprotected tropical forests are seriously threatened unless in the near future they are brought under sustainable management regimes. Despite national systems of protected areas, boycotts and threatened bans on tropical timber, and public concern about tropical deforestation, nevertheless, loss of tropical forests averaged 154,000 km^2 per year during the 1980s (125). Unless there is much greater effort and commitment to finding sustainable ways to use tropical forests, few unprotected tropical forests will survive far into the twenty-first century.

This chapter focuses on the status of ecological efforts to promote and test sustainable development in tropical forests. To put it simply: How can tropical forests be used without destroying them? Forest policy and socioeconomic aspects of forest use are treated only peripherally when they are regarded as relevant to this discussion. The classic literature on tropical silviculture is not reviewed here; readers interested in tropical forest management should consult the traditional literature (10, 34–36) as well as more recent holistic perspectives (20, 97, 126).

ECOLOGICAL BASIS AND CRITERIA FOR SUSTAINABLE FORESTRY

Several key ecological factors are critical to sustainable tropical forestry: reproduction and genetics; natural regeneration; growth; seed dispersal; seedling establishment; light regimes; ecological processes; and ecosystem functions. Biodiversity issues to be addressed include the effects of harvesting not only on the focal species, but on other dependent or independent species in the same ecosystem.

Reproduction

Focal species must be able to reproduce successfully. In the context of sustainable tropical forestry, however, there is an appalling dearth of scientific information on the reproductive biology of commercial timber species in natural forests (68). Key reproductive features such as phenology, breeding system, pollinator, seed disperser, and seed viability are known for few tropical forest species that are the source of timber or of nontimber forest products (11). The exceptions to this generalization are tropical forest species (e.g. *Bactris gasipaes, Tectona grandis, Theobroma cacao*) domesticated for plantation culture.

Understanding the reproductive biology of a focal species in natural forest may permit sustainable harvest, maintain dependent species, and minimize risk of extinction. But the harvesting of prereproductive individuals or all adults may drastically lower or abrogate seed production. Repetitive harvesting of all near-adult individuals dooms the population to extinction, analogous to harvesting a plantation. Ignorance of seasonality of reproduction can also have serious consequences. In the Amazon Basin, for example, mahogany (*Swietenia macrophylla*) is traditionally harvested from natural forests in the dry season, just before fruits mature and disperse the winged seeds at the end of the dry season (80). If a few seed trees were left or if mahogany harvesting could be delayed to later in the dry season or the beginning of the rains, far more viable seed would be naturally available for maintaining the population.

The concept of keystone species (111) in tropical forests has not been adequately explored, nor has its relevance to sustainable tropical forestry been evaluated. A keystone species provides critical food resources (usually fruit) that support populations of users (e.g. frugivore guild) during seasonal scarcity. In Manu, Peru, palms are the principal food source for monkeys during the annual period of food scarcity (112). Figs, with some individuals always in fruit, also often play a keystone role for the frugivore guild (122).

One should not assume that keystone species fulfill their eponymous function every year. Supra-annual fluctuations in seasonality, such as those associated with the El Niño-Southern Oscillation (ENSO) phenomenon, may have community-wide effects on phenology and food availability. The best documentation comes from the Barro Colorado Island research facility in Panama's Lake Gatún, where an ENSO-related weak dry season (e.g. 1958, 1970) precluded flowering and fruiting of several tree and liana species. The scarcity of fleshy fruits the following rainy season triggered famine among the frugivore guild (38, 66). Fluctuations in the seasonality of rainfall may be exacerbated by global climate change (53).

Reproductive capacity, whether sexual or vegetative, needs to be considered in assessing the threat of extinction as well as its relevance to any harvesting regime. The extreme example is monocarpic species that grow for many years before synchronously flowering and fruiting and then die (e.g. bamboos, talipot palm *Corypha umbraculifera, Tachigali* spp.). Overharvesting prereproductive individuals of monocarpic species can have devastating effects on the population. Massive, natural die-offs of postreproductive individuals can also have important conservation consequences, such as the bamboo die-off in central China that forced pandas to forage at lower, more accessible elevations, increasing their susceptibility to poaching and capture (106).

As suggested above, vegetative reproduction (67, 109) may be an important factor in sustainability. The Brazilian sassafras tree (*Ocotea odorifera*) is a primary source of safrol oil used in the manufacture of two chemicals, heliotropin (used as a fixative in the fragrance industry) and piperonyl butoxide (an enhancer of some insecticides like pyrethrins). Because *O. odorifera* occurs in the highly endangered Atlantic forests of Brazil, IBAMA (National Environmental Agency) lists it as an endangered species. Like many members of the Lauraceae, *O. odorifera* coppices vigorously from cut stumps, whether in primary forest, secondary forest, or even open pasture. Not only does stump-sprouting capacity offer an excellent opportunity for sustainable management of sassafras trees, it also suggests that in the dwindling Atlantic forests of Brazil, this species may well have the rare capacity to survive deforestation.

Natural Regeneration

Natural regeneration of commercial species has long been a principal focus and limitation of tropical forest management systems (19, 39, 43, 69, 105, 120). Though experts agree that adequate regeneration is a fundamental criterion of sustainability, the question is, how much is adequate? Sampling the number of seedlings or saplings of the focal species may be a poor predictor of future stocking of harvestable individuals. In natural habitats like tropical forests, most plant populations go through a fairly restrictive bottleneck in their life cycle, usually in the seed or seedling stage (45, 58). A reproductive plant may produce copious seeds of low viability, resulting in very few seedlings. More commonly, viable seeds require specific microsite conditions such as moisture or heat (e.g. *Ochroma lagopus* seed germination is favored by high temperatures) or chemical or physical scarification through a disperser's gut (119). An extreme example of the latter is *Calvaria*, a Sapotaceae tree endemic to Mauritius. Only large trees now exist and they fruit abundantly, but the seeds do not germinate. Seeds that pass through domestic turkeys do germinate, suggesting that this tree species may have depended on the dodo (*Raphus cucullatus*), extinct since 1681 (76).

In neotropical forests, high densities (> 10/m^2) of seedlings are sufficiently uncommon to be noticeable. Tropical forest species with abundant seedlings seem to have very tiny seeds of short viability (e.g. *Vochysia* spp.) or large, chemically protected seeds (e.g. *Pentaclethra macroloba*). Unusually dense carpets (> 100/m^2) of seedlings under the parental crown (e.g. *Ampelocera macrocarpa,* some Sapotaceae) suggest that important seed dispersers/predators are missing from the forest habitat (64).

A contrasting pattern of supra-annual, synchronous mast fruiting is well known for the dipterocarp forests of Southeast Asia (124). After skipping several years, numerous species among several genera of the dominant tree family, Dipterocarpaceae, synchronize fruit maturation, which has the effect of satiating seed predators. Many seed eaters such as hornbills (Bucerotidae) and wild boar (*Sus scrofa*) migrate as they track mature fruit. Due to the relatively long interval between mast crops by canopy dipterocarps, adequate regeneration of the commercial species is a key prelogging requirement of the Malayan Uniform System (7, 10). Unfortunately, logging companies do not always respect the regeneration requirement.

Once forest seedlings have exhausted their seed reserves, they come under fierce competition for light, nutrients, and moisture and are subject as well to attack by herbivores and parasites. The net result is usually such a drastic reduction in numbers that, by the sapling stage of a plant's life cycle, numbers of juveniles in the population may be inadequate to replace harvested adults. The forest managers' preoccupation with inadequate regeneration of focal species has prompted considerable investment in enrichment planting.

Because of low density of adults and poor natural regeneration, selectively logged forests have been enriched by line-planting of high value species, such as mahogany (*Swietenia macrophylla*). To provide the more favorable light regime that mahogany requires, broad lanes (ca. 2 m wide) are cut through the forest understory for planting nursery-grown seedlings. Provided there is an acceptable match of species to site, enrichment planting is usually successful in establishing vigorous saplings. However, enrichment planting is seldom viable economically, because of the cost of frequent weeding to favor the planted trees.

In contrast to the long tradition of species-based tropical silviculture, research on tropical forest dynamics prompted a more holistic, community-level perspective on the role of tree falls (gaps) in natural regeneration of native tree species (113). Several studies of neotropical forest dynamics [for trees > 10 cm diameter at breast height (dbh)] indicate high turnover rates of 75–150 years (51), tree mortality rates of 1–2% per year (51), stand half-life of 38–50 years (73), and high species-dependence on gaps for successful establishment

(17, 30, 48). Researchers over the past three decades have illuminated the central role of disturbance in the dynamics and regeneration not only of tropical forests, but also of many other biomes as well (92). The focus on natural regeneration of trees in tropical forests contributed substantially to the development of the intermediate disturbance hypothesis for maintaining high species diversity (27, 63). Frequent, stochastic disturbance is theorized to preempt competitive exclusion of gap opportunists from complex communities (25). The role of disturbance in community dynamics, natural regeneration, and maintenance of diversity continues to attract much research (31).

As concern mounted in the late 1970s over tropical deforestation, I realized that the revisionary thinking about gap dynamics might have potential to improve tropical forest management. I proposed simulating gap dynamics by clear-cutting long, narrow strips in tropical forests suitable for production forestry (46, 49). Because approximately half of the native tree species in the La Selva (Costa Rica) forest depend on gaps for successful establishment, I reasoned that simulating gaps could stimulate natural regeneration of many tree species. The La Selva research shows that a higher proportion of canopy tree species require gaps than do subcanopy or understory tree species (50). Also, many valuable tropical timber species are dependent on gaps (e.g. *Cedrela odorata, Cedrelinga catenaeformis, Swietenia macrophylla*). A commercial application of the gap-based model of tropical forest management is described below in the Sustainable Forestry Models section.

Growth Rates

Extremely slow growth rates of many tropical trees in primary forests are perceived as a major impediment to sustainable tropical forestry. Growth rates ranging from 0 to 10 mm of annual diameter increment mean a tree must be many decades old before it attains harvestable size. The combination of slow growth rates of valuable timber species in natural forests (73) and inadequate natural regeneration of valuable timber species discouraged many tropical foresters from seriously considering production forestry as a viable use of complex tropical forests (cf 72). Yet these growth rates seemed incongruous with the dynamic filling of gaps in the forest canopy. Gap-dependent, light-demanding tree species can attain the canopy (30–40 m) in 10–20 years, demonstrating not only rapid height growth, but appreciable diameter increment as well (74). Gap species are prime candidates for plantation forestry and enrichment planting, too.

Though favorable light regimes in gaps, strips, or second growth areas often promote rapid growth of trees, climbing vines and scandent shrubs grow even faster. These dependent plants can quickly overtop gaps as well as trees. Even canopy emergents can be festooned with lianas that often drastically reduce the seed production of large trees. Robust lianas interlinking canopy tree crowns not only may reduce growth, they may also complicate the selective felling of trees. Thus, "climber control" is an integral part of preharvesting and silvicultural treatments of natural forests (6). Cutting of large lianas 6–18 months before tree felling is a common prescription to facilitate the felling and to minimize damage to forest structure. Similarly, the periodic control of woody climbers in simulated gaps and young secondary forest is essential to promoting good growth of young trees.

Lack of ecological information about liana species is a major constraint to sustainable development of nontimber forest products. With the notable exception of the more important rattan species in southeast Asia, even less is known about the ecology of lianas than of canopy trees in most tropical forests (101). The fact that some lianas (e.g. *Chondrodendron* spp., *Uncaria* spp.) have extraordinary pharmaceutical properties has resulted in the uncontrolled harvest of these species (J. Duke, personal communication); such harvesting, combined with lack of cultivation, may threaten their survival.

Biodiversity Conservation

In most tropical countries, production forestry and biodiversity conservation are considered inimical (or incompatible), and the responsible national agencies are usually in different ministries (13). However, if sustainable tropical forestry could maintain natural forest habitats, harvesting timber or nontimber forest products could be compatible with biodiversity conservation objectives (86, 87, 98). Most developing countries in the natural range of tropical forests have 2–10 times as much area of tropical forests remaining as has been designated in national parks and equivalent reserves (125). [However, most countries with tropical forests also have less than the recommended 10% of the national territory in protected areas (60).] Thus, the development of sustainable production systems for timber and/or nontimber forest products that maintain natural forests could complement the national system of protected areas for the conservation of biodiversity.

Selective logging of high-value timber usually has serious repercussions on forest biodiversity (32). Logging roads provide access for hunters, poachers, miners, farmers, and colonists. Even subsistence hunting can decimate populations of larger vertebrates (65). Enforcement of regulations is often so weak or nonexistent that even though logging per se does not destroy the forest, the accompanying defaunation and deforestation tend to have disastrous effects on biodiversity (102, 103).

Ethnobiologists are finding that indigenous tribes manage forest succession to enhance abundance of useful plants (9). They may plant or favor medicinal plants and fruit trees in their garden plots so that preferred species are available or attract game animals. Indeed, there is growing evidence that indigenous people have had a more profound effect on primary forest composition and structure than was previously thought (e.g. 44).

Efforts to design and test sustainable development models for tropical forest products have been almost entirely entrepreneurial. While recent research has tended to focus on timber vs. nontimber uses (91), one of the great challenges for sustainable tropical forestry is to integrate timber and nontimber forest production. The community-based management of forest products such as bushmeat, medicinal plants, fibers for basket weaving, and edible fruits could diversify the resource base and add value to forest products. Most community-based initiatives currently focusing on nontimber forest products tend to target limited markets, with modest economic benefits. Generating significant economic benefits for local communities is a major problem with most ecotourism initiatives as well (see below).

Ecosystem Functions

In addition to providing renewable commodities and supporting biodiversity, tropical forests have several important ecosystem functions. Tropical forests protect watersheds, reduce soil erosion, and stabilize local and global climate, inter alia. Though these key ecosystem functions can be achieved to a substantial degree by tree plantations, they are most efficiently met by intact natural forests with their multiple layers of vegetation and full complement of wildlife—both vertebrate and invertebrate (99). Yet these critical ecosystem functions are ignored in national development planning and by local landowners.

Catchment forests are critically important to many hydrologic functions. On front ranges—where they are often called cloud forests—they intercept moisture-laden clouds, adding appreciable condensation drip to normal precipitation. The characteristic abundance of epiphytes, particularly mosses, in cloud forests greatly increases the surface area for moisture condensation. Because many important watershed catchments are at cooler, mid-elevations (ca. 1000–3000 m), organic matter accumulates on the soil surface and in the upper soil layer (79). Not only do epiphyte-laden catchment forests intercept much moisture, but also the abundant organic matter on and in the forest soil functions like a gigantic sponge in absorbing the heavy rainfall. Catchment forests are particularly effective in modulating stream flow, reducing peak flows during high rainfall periods, and releasing groundwater during seasonal drought. The maintenance and protection of forests in watersheds feeding reservoirs, not surprisingly, should be a top priority; however, many developing countries continue to ignore the critical hydrologic functions of forest catchments until drought or flooding brings the lesson home.

Forest cover protects soil from the erosive forces of rainfall and surface runoff. Deforested slopes may suffer soil erosion two orders of magnitude greater than that in comparable sites with forest protection (115). Even on steep slopes, forests are amazingly tenacious, not only minimizing soil erosion, but also reducing the incidence of landslips and-slides. Mechanized logging causes considerable soil disturbance (78). Though reforestation can lessen soil degradation as well as rehabilitate soil productivity, much degradation occurs during the landscape conversion process and in the early establishment phase of plantations. Landscape and national level classification of land-use potential is fundamentally important to identifying and zoning landscapes unsuitable for agriculture (sensu lato) that should remain in protective forests. Human population growth, inequitable land tenure and access, failed agrarian reform, and national colonization and development programs force rural farmers onto steeper slopes and farther upstream in important watersheds.

The cutting and burning of tropical forests contribute 20–25% of the greenhouse gases accumulating in our planet's atmosphere; hence, these are significant factors in global climate change. The substantial areas of unprotected forests in forest-rich countries, and the national efforts to convert these forests to pasture or agriculture, suggest that tropical deforestation will continue to be an important factor in global climate change. Sustainable development justifications for protecting tropical forests are a high priority for development assistance agencies and international conservation organizations.

An ecosystem function often overlooked in sustainable tropical forestry initiatives is the role of mycorrhizae (61). There is some evidence that logging may depress mycorrhizal inoculation potential for seedlings (2). Obligate mycorrhizal associates may be essential to sustainable forest management systems (62).

SUSTAINABLE FORESTRY MODELS

The very few commercial forestry operations that have been certified as sustainable sources of tropical timber indicate the paucity of successful models of sustainable forest management. In fact, much has been written about sustainable forestry issues, but there are few documented sustainable models. Almost by definition, industrial harvesting of tropical timber is not sustainable, because it is essentially a mining operation to extract only the most valuable timber (83, 85, 116). Even with national laws and regulations requiring an investment in postharvest silviculture to ensure future timber harvests, such investment seldom happens. That is why the most interesting models of sustainable tropical forestry are small-scale initiatives at the community or small-landowner level (89, 100). Scaling up these small, local pilot projects to commercially significant levels is a great challenge (40). Because alternatives to timber [or nontimber forest products (NTFPs), as they are popularly termed] are generally not of interest to timber companies, a great array of NTFPs are attracting considerable interest as a source for local community development. Finally, nature-based tourism (or ecotourism) attempts to capitalize on the burgeoning interest in tropical forests and wildlife.

Industrial Timber Production

Concessionary arrangements, which are the dominant mode for producing industrial timber from tropical forests, have been severely criticized for policy and practices antithetical to sustainable tropical forestry (71). Generally, a government grants a timber-harvesting concession to a commercial company for a moderate period (one to a few decades). There are many things wrong with the concessionary approach to tropical forestry, such as little or no incentive for the concessionaire to invest in or practice sustainable forestry, a mining approach for valuable timbers, token royalty charges for stumpage, and ignorance or abuse of local rights and tenure (75).

The Costa Rican company, PORTICO S.A., has made an unusual commitment to sustainable forestry by managing its own forests on a sustainable basis. Through enlightened leadership in the mid-1980s, PORTICO used a debt-for-equity swap with a US bank to purchase several thousand hectares of production forests in northeast Costa Rica, to buy and upgrade two sawmills, and to expand and modernize their hardwood door manufacturing plant. By 1988 PORTICO was exporting 65,000 hardwood doors, primarily to the United States.

Because most of Costa Rica is privately owned in relatively small holdings, PORTICO bought several properties, mostly in the 100–500 ha range. A novel approach was to purchase only the forested portions of these properties, leaving the seller's working farm not only intact, but with an infusion of capital. Thus, the purchase of production forests by PORTICO did not expel local people. In fact, many local residents were able to find off-farm employment with PORTICO forestry operations.

Carapa nicaraguensis (Meliaceae) is the principal timber tree used by PORTICO, marketed under the trade name "royal mahogany." Trees of this species dominate the swamp forests of northeast Costa Rica, where they can attain 200 cm dbh and a height of 45 m, with commercial volumes averaging 40 m^3/ha. Furthermore, *C. nicaraguensis* (formerly called *C. guianensis* in Central America) has prolific natural regeneration of seedlings (81). Thus, it is an ideal candidate for sustainable forest management.

PORTICO developed a comprehensive forest management plan for each property, which is managed as a production unit. These management plans are based on detailed stand inventories of timber volume by species, diameter-class distribution, and regeneration status. Early harvesting was done by contract loggers, who caused considerable damage to the residual stand by indiscriminate felling and skidding. A switch to employee logging coupled with field training in directional felling and minimal skidding of logs greatly reduced logging damage. This is vitally important to the long-term sustainable production of timber from such forests.

PORTICO has made a major commitment to research and to monitoring in its production forests (12). It has long-term control plots (each 1–4 ha) to monitor natural growth and mortality in unlogged or managed forests. These complement many other plots in which the effects of felling and skidding damage are assessed and experimental silvicultural treatments such as thinning of competing individuals are monitored. Research results support the management plan (R. Peralta, PORTICO Director of Research, personal communication). An interesting internal analysis indicates that PORTICO's investment in research approximately doubles the cost of its timber; however, the vertical integration of production enables the higher costs of raw material to be absorbed and covered by the export sale of the final product (L. Torres, PORTICO President, personal communication).

The conservation of biodiversity is an integral component of PORTICO's forest management (23). The company actively patrols its properties and effectively prohibits hunting in the forests. As part of company-sponsored biodiversity inventories, we found more wildlife in recently logged, managed forests than in the adjoining Barra del Colorado Wildlife Sanctuary, presumably due to better protection from hunting in the former (G. Hartshorn, unpublished). The company has a formal collaborative agreement with the National Biodiversity Institute (INBio) for biodiversity inventory and monitoring research. PORTICO is also responsive to recommendations for better integration of production forestry and biodiversity conservation. For example, when we recommended that the company exclude all *Dipteryx panamensis* trees from harvesting because this tree's fruits are a prime food for endangered green macaws (*Ara ambigua*), PORTICO immediately banned logging or damage to all mature *Dipteryx* trees in its production forests.

Community-Based Timber Production

The involvement of local communities in sustainable forestry traditionally focused on nontimber forest products (see below). Only in the past decade have some communities embarked upon direct involvement in the sustainable production of tropical timber (8, 89). One innovative approach is the Yánesha Forestry Cooperative (COFYAL) in the Peruvian Amazon (52). COFYAL was created through the joint efforts of USAID and the Peruvian government to bring sustainable development to the Palcazú Valley in the Central Selva region. Originally conceived as a traditional rural development project to assist colonists with agriculture and livestock, the USAID-funded environmental assessment of the proposed project concluded that conventional approaches would fail. The recommended alternative of sustainable forestry was accepted.

A contemporaneous social soundness analysis of the proposed rural development project noted that the Palcazú Valley is home to the last native communities of Amuesha Indians, an Arawakan indigenous group compressed into the central and southern part of the lower Palcazú Valley (110). In the loan agreement with the Peruvian government, USAID required that, prior to disbursing loan funds, all native community land claims be officially recognized and legally titled. The Peruvian government complied, recognizing 11 native communities of Amuesha Indians in the Palcazú Valley. When the Palcazú project started in 1984, the Amuesha comprised about 60% of the Valley's 5000 inhabitants. Initial surveys of land-use capability and location of production forests in the lower valley indicated that the extensive native communities held most of the remaining forests suitable for production forestry.

In part because Peruvian law recognized only agricultural cooperatives, it took two years to obtain official status for the Yánesha Forestry Cooperative (COFYAL), founded by 70 individual Amueshas and five native communities. (Yánesha is what the Amuesha call themselves, whereas the latter name is how they are known in Peru and in the anthropologic literature.) The objectives of COFYAL, the first forestry cooperative in South America, are to: 1) provide a source of employment for members of the native communities; 2) manage the communities' natural forests for sustained yield of forest products; and 3) protect the cultural integrity of the Yánesha people.

All forest management and timber production is under the control of COFYAL. COFYAL adopted the strip-cut technique for managing complex tropical forests (49, 55). To improve use of timber from the strip cuts, technical advisors to the project designed complementary local processing technologies to be managed by the local landowners (114). On land ceded by the Shiringamazú native community, the cooperative has two sawmills, a bank of 44 pressure caps for preservation of poles and posts, a portable charcoal kiln, and the appropriate supporting equipment. Local processing, in combination with access to national and regional markets, enables COFYAL to process and sell most of the wood harvested from the production strips.

The strip-cut technique is the ecological cornerstone of COFYAL's sustainable forestry initiative. Strip cuts promote outstanding natural regeneration of hundreds of native tree species (54). Even with occasional thinning, only a handful of tree species have been lost from the regenerating strips. The strips may enhance biodiversity conservation by providing more appropriate regeneration sites for rare tree species; for example, I found four seedlings of *Minquartia guianensis* on two demonstration strips, yet I could not locate a parent tree within 500 m. Early growth rates in combination with silvicultural release suggest that a projected 30–40 year rotation may be attainable.

Though COFYAL's progress and success have been severely compromised by the 1988 pullout of USAID, occasionally lengthy shutdowns due to national conflicts and local outbreaks of terrorism, and lack of financial and technical support, still the cooperative survives. The resiliency of COFYAL epitomizes the importance of a transdisciplinary approach to sustainable tropical forestry, where the activities must be ecologically sound, economically viable, socially responsible, and politically acceptable.

Community-Based Production of Nontimber Forest Products

The diversity of nontimber forest products (NTFPs) spans the spectrum of tropical biodiversity: bamboo, bark, bird nests, bushmeat, dyes, eggs, feathers, fiber, fish, fodder, fruits, fuelwood, gums, heart of palm, hides, honey, lac, latex, leaves, live animals, medicines, mushrooms, nuts, oils, ornamentals, rattans, resins, spices, thatch, and vines. A remarkable array of NTFPs have been harvested for centuries or millenia by traditional hunter-gatherers (e.g. 3, 16, 57, 82, 90, 117, 118). This last half-century has seen NTFPs become important commercial commodities as well (42, 84). With few exceptions (e.g. rattan), NTFPs are secondary in economic importance to timber. Though commercial logging activities may destroy some NTFPs, the purported lower economic value of the NTFPs plus their more intensive labor requirements and unsuitability for mechanized extraction of NTFPs often relegate or assign them to local communities.

Over the past decade there has been an increase of research and development interest in NTFPs, with particular emphasis on bringing greater economic benefits to local people. Initially, research efforts focused on valuation of NTFPs (29, 91). The rapid and substantive involvement of cultural anthropologists has broadened the NTFP issue to address indigenous rights, tenure, and local empowerment (26, 75, 93). Thus, the control, use, and marketing of NTFPs have become critical factors in the local empowerment of forest dwellers, ethnic groups, and local communities (4, 21).

Government designation of vast extractive reserves in Brazil and Colombia has received much attention (37, 104, 107). Brazil's extractive reserves total over 20,000,000 ha in the Amazon Basin, primarily benefiting local rubber tappers who maintain an extensive network of forest trails to tap wild rubber trees (*Hevea brasiliensis*) during the rainy season. Rubber tappers collect Brazil nuts during the dry season. The development of local processing capacity and more direct access to markets are key factors in improving the economic returns to local communities (26).

Before World War II, forest dwellers in Southeast Asia had vast areas of primary forest from which to collect NTFPs, but those who mechanized logging of the valuable dipterocarp forests ignored or abused local people while they opened up logged-over areas for shifting cultivation and promoted human migration. Depletion of and reduced access to NTFPs fueled greater community involvement in forest protection. Joint community management has become national policy in India (94, 95). Local communities have successfully rehabilitated degraded forests and improved watershed protection in northern Thailand (24). Even in forest-rich countries like Indonesia, local communities are protecting their traditional forests and NTFPs (1). Scarcity of forest land and severe watershed degradation in the Philippines is opening the door for community coordination and initiatives to maintain the few remaining forests and to rehabilitate the extensive degraded landscapes with NTFP species (121).

Despite the surge of interest in NTFPs and many new projects to promote NTFPs as the economic basis for local community development, little ecological information is available about the focal species (cf 47, 70). What are sustainable harvest levels? Where are the population bottlenecks? How can populations be enhanced? How can NTFP species be managed in rebuilding forests? Many of these fundamental ecological questions need to be answered if sustainable commercial production of NTFPs is to benefit rural communities.

Locally Controlled Nature Tourism

Nature-based tourism (or ecotourism, as it is popularly known) is usually portrayed as the most benign economic use of natural habitats, simply because no products are removed (123). Ecotourism is defined as travel to relatively undisturbed or uncontaminated natural areas with the specific objective of studying, admiring, and enjoying the scenery and wild plants and animals, as well as any cultural manifestations (both past and present) found in those areas (22). Nature-based tourism has boomed in countries such as Thailand, Kenya, and Costa Rica, while many developing countries are promoting tourism as an attractive development option (15). In the rush to cash in on the global tourism boom, however, the involvement and interests of local communities tend to be overlooked or overridden by outside economic powers. Though proponents of ecotourism have focused on the potential benefits for protected areas, ecotourism does not have to be restricted to formally designated national parks and equivalent reserves. Hence, tropical forests with intact wildlife or scenic features are potentially attractive to tourists and could more easily generate economic returns to local communities than do traditional rural development projects.

Ecotourism brings economic benefits in four ways: 1) It is a growth industry; 2) the market comes to the resource; 3) tourism helps diversify the economy; and 4) it stimulates economic growth in rural areas (14). However, the environmental impacts of ecotourism, or more importantly, significant growth in ecotourism, are poorly known and largely unstudied. For example, what is the area's carrying capacity for tourists? How can infrastructure mitigate the environmental impacts of increased tourism? What are the environmental tradeoffs of growth in ecotourism? For popular sites, how can increasing visits and higher expectations be managed?

Local entrepreneurs can play a leadership role in meeting the increasing needs and expectations of ecotourists, as well as diversifying the attractions and opportunities for tourists (33). The importance of local initiatives is demonstrated by world-class nature attractions like Costa Rica's Monteverde Cloud Forest Reserve, Nepal's Royal Chitwan National Park, and Thailand's Khao Yai National Park. Active community involvement in diversifying lodging choices, promoting local crafts and artisans, providing music festivals adjacent to scenic areas, offering local nature guides, etc, not only strengthens the local economy, but often has a synergistic effect on local support for the focal natural resources (56).

Another area in which nature-based tourism offers potential synergies is with research. The recent surge in safer, less rigorous access to forest canopies is helping to protect several tropical forests while providing researchers with better and easier access to the last terrestrial frontier of tropical biology. In northeast Peru, the Amazon Center for Environmental Education and Research (ACEER) has constructed a 450 m walkway through the tropical forest canopy. Though nature tourists and educational groups are the primary users of the walkway, researchers are finding it attractive, too. For example, the beaver-tailed lizard, *Uracentron flaviceps*, was presumed to be extremely rare because only a few specimens exist in the world's herpetological collections. It turns out to be quite common in the ACEER forest along the canopy walkway.

CONCLUSIONS

Sustainable development is critical to the survival of most unprotected tropical forests. The physical, political, and/or legal owners of tropical forests insist that these sometimes vast natural resources be used for development objectives. However, traditional development for pastures or agriculture is synonymous with deforestation. Sustainable development in tropical forests is a new paradigm that attempts to integrate forest conservation and economic development.

Biological and ecological factors critical to sustainable tropical forestry include: reproduction, natural regeneration, growth, and ecosystem functions. Though a few plant species successfully maintain populations through vegetative reproduction, the production of seeds and seedlings is fundamental to most sustainable harvesting systems. Inadequate natural regeneration long constrained attempts to manage complex tropical forests; however, recent advances in our understanding of gap dependency offer new hope for successful establishment and growth of preferred species. The selective harvesting of timber causes considerable damage to tropical forests, as well as opening the forests for uncontrolled hunting and land clearing. Tropical forests have important but little appreciated ecological functions in watershed and soil protection, local rainfall regimes, and global climate change.

Four models of sustainable tropical forestry are discussed: industrial timber production, community-based timber production, community-based production of nontimber forest products, and locally controlled nature tourism. More has been written about the merits, definition, and criteria for sustainability than has been devoted to documenting sustainable models of tropical forestry. Many of the more interesting models involve local communities, whether they focus on timber, nontimber forest products, or ecotourism. Industrial timber production from tropical forests is largely through government concessions and almost by definition nonsustainable, because of the short time period and minimal investment in future harvests.

The Costa Rican door manufacturing company PORTICO is unusual in many respects: It owns its own production forests; it manages its forests on a sustainable basis; it invests in directed research; it effectively protects biodiversity; and its wood utilization is vertically integrated. PORTICO's primary timber species, *Carapa nicaraguensis,* dominates its forests, and produces abundant seedlings and adequate growth.

The Yánesha Forestry Cooperative in the Peruvian Amazon is an innovative approach to community-based timber production. The Coop adopted the strip-cut forest management technique that promotes excellent natural regeneration of hundreds of native tree species. Local processing of timber for sawnwood, preserved poles, and charcoal enables the Coop to use nearly all of the native timbers and to generate attractive economic returns.

Nontimber forest products traditionally have been key to the subsistence of local communities. Much effort is now going into determining commercial potential, sustainable harvesting levels, and market opportunities for several nontimber forest products. These forest commodities are increasingly important in strengthening local control of and access to tropical forests. Much more research is needed on nontimber forest products for them to play a more important role in sustaining tropical forests.

Nature-based tourism (or ecotourism) is considered the most benign use of tropical forests because no products are removed. National and local booms in ecotourism tend to ignore or marginalize local communities from decision-making, as well as from receiving appropriate economic returns. The most attractive sites face problems in determining how many visitors can be handled and how to mitigate the environmental impact of increased tourism. Synergies between ecotourism and field research are beginning to occur, particularly with the rapid development of safer techniques to access the forest canopy.

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