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# Natural Forest Management and Conservation of Biodiversity in Tropical Forests

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**Abstract:** As a reaction to the continued dwindling of tropical forest resources, many research and development organizations have turned to the idea of natural forest management in the hope of making tropical forest lands more profitable while maintaining biodiversity. Assertions of sustainability in logging practices have been inadequately supported, however. We begin with a review of the present knowledge of the effects of logging operations on various organisms. Post-harvest surveys of a spectrum of tropical forests indicate a range of logging effects from local extirpation to substantial increases in local densities of some species. The state of our knowledge does not permit quantitative predictions, but logging at any level appears to have simplifying and homogenizing effects on tropical forest diversity when examined at community or regional scales. Furthermore, the social and economic problems presented by natural forest management systems have not yet been adequately addressed. We present alternatives to the strong emphasis on "sustainable natural forest management" as a means of retaining the diversity of tropical forest communities. These alternatives include increased support for management of secondary forests, restoration of degraded lands, plantation forestry, nontimber uses for some forests, changes in accounting procedures to reflect the true value of natural forests, and support for forestry agencies charged with protecting forest reserves.

Manejo de Bosques Naturales y Conservación de la Biodiversidad en Bosques Tropicales

**Resumen:** Como una reacción a la constante reducción de los recursos en bosques tropicales, muchos investigadores y organizaciones de desarrollo se han enfocado en la idea del manejo de bosques naturales, con la esperanza de que las tierras con bosques tropicales sean más rentables, al mismo tiempo que se pretende mantener la biodiversidad. Sin embargo, algunas aseveraciones de sustentabilidad en prácticas de tala han sido inadecuadamente soportadas. Iniciamos con una revisión del conocimiento actual de los efectos de operaciones de tala en varios organismos. Estudios posteriores a las cosechas en un espectro de bosques tropicales indican que el rango de efectos de la tala varían desde la extirpación local hasta el incremento sustancial en la densidad local de algunas especies. El estado actual de nuestro conocimiento no nos permite realizar predicciones cuantitativas, pero la tala a cualquier nivel aparenta tener efectos de simplificación y homogeneización en la diversidad de los bosques tropicales cuando se examina a nivel de escala regional. Mas aún, los problemas sociales y económicos en sistemas de manejo de bosques naturales no han sido abordados adecuadamente. Presentamos alternativas para el enfatizado "manejo sustentable de bosques naturales" como una medida para retener la diversidad de las comunidades de bosques tropicales. Estas alternativas incluyen un soporte mayor en el manejo de bosques secundarios, la restauración de tierras degradadas, plantaciones forestales, usos diferentes a la tala en algunos bosques, cambios en los procedimientos de contabilidad para reflejar el valor verdadero de los bosques naturales y soporte en las agencias forestales encargadas de la protección de las reservas forestales.

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## Introduction

Despite increasing concern over the loss of tropical forests and despite significant local and international efforts to find solutions to the problem, the rate of deforestation in the tropics continues to increase. The 1990 forest assessment conducted by the United Nations Food and Agriculture Organization (FAO) indicated a mean annual tropical deforestation rate of 0.8% during the 1980–1990 decade, as compared to 0.6% during 1976–1980 (Food and Agriculture Organization/United Nations Environmental Programme 1981; World Resources Institute 1994; Food and Agriculture Association 1995). Even in a country such as Costa Rica, considered in some respects a model of conservation, annual deforestation exceeds 4.2% (World Resources Institute 1991; Solórzano 1995; Sanchez-Azofeifa 1996). The search for sustainable solutions to these high rates has focused on various forms of natural forest management. In simplest terms, natural forest management (NFM) involves the harvesting of trees in such a way as to allow the forest to regenerate naturally before the next round of extraction. In other words, NFM relies on the inherent regenerative powers of the forest as opposed to extensive silvicultural intervention. Although some have criticized the term *natural forest management* as undefined or oxymoronic, we use the term here because it is used conventionally in tropical forestry to distinguish a range of relatively nonintensive management modes from more-intensive plantation forestry. The various types of NFM differ in the intensity and the spatial and temporal patterns of logging and in the kinds of silvicultural treatments practiced before and after logging (Baur 1964; Schmidt 1987; Buschbacher 1990; Hartshorn 1995; Bruenig 1996). There is an implied or explicit connotation of sustainability in the commonplace usage of the term NFM.

In recent years NFM has become the centerpiece of forest-sector activities of international development organizations, donor agencies, and governments, as well as national and international research organizations (Poore et al. 1989; Center for International Forestry Research 1993; United Nations Food and Agriculture Organization 1993; International Tropical Timber Organization 1994; Lanly 1995). The modern versions of NFM that emphasize low-impact logging are not fundamentally different from older systems that have been practiced in parts of the tropics for more than 100 years. It is presumed, however, that by reducing the physical impact of logging, NFM can be made more benign to the environment than were past systems (Buschbacher 1990; International Tropical Timber Organization 1994). Three assumptions commonly underlie modern concepts of natural forest management: (1) management can be exercised in a manner compatible with the *maintenance of biodiversity*, (2) management of tropical forests, despite their high diversity on local and regional scales, is

*economically viable*, and (3) management can result in *sustained timber yields* over the long term. Of these assumptions, the first is critical to the continued viability of the forest as a system because the loss of biodiversity is believed to have a negative influence on the functioning of the ecosystem as a whole (Lamprecht 1989; Lawton 1997; Tilman 1997). Concern over the loss of biodiversity, particularly genetic resources, has been a driving force behind efforts toward NFM. Therefore, management systems that seek to maintain biodiversity ought to be preferred.

We evaluated the key assumptions underlying the renewed emphasis on NFM as a means to conserve biodiversity and sustainably use tropical forest resources. We believe that the concepts of NFM, sustainability, and conservation of biodiversity have often been conflated without a rigorous examination of the relationships among the three. In particular, we address the following questions: (1) Are the goals of NFM and conservation of biodiversity truly compatible in the long term? (2) Can tropical forests be managed, in the long term, on an economic basis? (3) To what extent is the concept of sustained yield valid for different types of tropical forests, including both primary and secondary forests? Because NFM is emerging as the focal point of activities of many national and international organizations, it is appropriate to ask if this emphasis is justified, particularly in the light of a multitude of other pressing needs in the conservation and management of tropical forests. We conclude that emphasis on NFM as a means to sustainably use tropical forests and to conserve biodiversity is not supported by the available evidence and that there is a danger this emphasis may be detracting from other options available for conservation, management, and utilization of tropical forest resources.

The tropics comprise a multitude of different forest types with very different ecological characteristics, including dry forest, mangrove, and high-altitude oak forest. We have restricted our discussion to lowland and mid-altitude moist forests because these represent the largest fraction of tropical forest remaining worldwide. Other tropical forest types, such as tropical dry forest, have already been virtually eliminated throughout their ranges (Janzen 1988).

## Natural Forest Management and Conservation of Biodiversity

The impact of logging on biodiversity depends both upon the intensity of logging—particularly the number of stems extracted per unit area—and the amount of care and planning that goes into the extraction process. Although there is an extensive and expanding literature on the effects of logging on the distribution and abundance of plant and animal species, most of these studies de-

scribe the effects of mechanized, commercial logging operations. Some have advanced claims that commercial logging systems, such as those officially advocated in Malaysia and Indonesia, already constitute "sustainable" forestry; others deny this (Colchester 1990; Boot & Gullison 1995; Lugo 1995). Studies that have examined the results of carefully controlled, low-impact logging have not done so with biodiversity conservation primarily in mind (e.g., Quiros & Finegan 1994). In addition, such studies have been done on relatively small plots, in contrast to the extensive areas of forest open to commercial exploitation. Thus, the data we summarize are derived from studies that span the gamut of management styles, from low-intensity selective logging without further management intervention to systems involving relatively high-intensity logging and some silvicultural treatment.

### Structural Alterations

The immediate effects of a logging operation in a primary tropical forest consist of significant alterations to the physical structure of the forest. Removal of as few as 3.3% of the trees in an area can reduce canopy cover by 50% (Johns 1988; Uhl & Vieira 1989), and disturbance to canopy up to 75% is not uncommon (Cannon et al. 1994). At the other extreme, damage to basal area as little as 4–5% has been documented when only 0.12 mahogany trees per hectare are removed (Gullison & Hardner 1993). Quiros and Finegan (1994), on the other hand, document a carefully planned and managed experimental operation in Costa Rican premontane tropical wet forest in which 6.5% of the total basal area was harvested (leaving 58% of commercially utilizable volume as seed trees to protect hydrography and minimize soil erosion), while incidental damage was restricted to a mere 4.8% of basal area. In more conventional operations, the impact on undergrowth can also be substantial: in a logged area in Neotropical French Guyana, 38% of the undergrowth was destroyed during the removal of three trees per hectare (Thiollay 1992). The opening of the canopy can result in changes to the biophysical conditions of the forest, including the soil. Soil structure can be modified by compaction and drying, which may in turn have negative effects on the recruitment rates of trees (Malmer & Grip 1990; Johnson & Cabarle 1993).

Structural alterations may affect biodiversity values in a wide variety of ways. Logging disturbance typically results in a landscape of patchily distributed areas characterized by different degrees of canopy opening (Cannon et al. 1994). Some inaccessible areas (swamp land, ridges, gullies) may remain unlogged and retain an intact canopy structure. Because tree growth and animal populations respond differently in different areas, it is important to maintain a landscape-level viewpoint in evaluating the effects of management.

### Changes in Species Abundance and Species Composition

Several studies document a decline in number of large tree species after logging (Okali & Ola-Adams 1987; Primack & Lee 1991). Even when there is a minimum of mechanization and relatively little incidental damage during extraction (Ganzhorn et al. 1990), there are declines in overstory tree size, increased abundance of a few small-stemmed species, and a decrease in larger commercial species even several decades after a logging event. In other cases, the overall number of tree species remains the same but species composition changes in favor of pioneer species (Primack & Lee 1991). In the moist forests of the Western Ghats in India, early successional species were shown to have increased significantly in logged plots 10–15 years after logging, although the species richness of trees greater than 10 cm diameter at breast height was the same as before logging (Pomeroy 1996). Ashton has pointed out that localized increases of plant species diversity are inevitable following logging because logging expands the area of forest occupied by early successional phases, boosting representation of pioneer species in small samples (P. Ashton, personal communication). These local increases in diversity are not matched on the regional level, however, because the local increases come from the regional pool. Thus, logged forests tend to become increasingly homogeneous on a larger scale (Wyatt-Smith 1987).

The effects of logging on bird species are variable. Certain feeding guilds experience a collapse in population densities ranging from 25% to 100% loss in the affected area. These hard-hit guilds include terrestrial foragers (insectivores and frugivores), large arboreal frugivores (game birds), and the small insectivorous species associated with understory habitats, particularly those of the forest interior (Johns 1992; Thiollay 1992). Such decreases are likely the result of separate proximate causes: hunting on the one hand and a reduction in the insect resource base or microhabitat changes on the other (Frumhoff 1995; Johns 1985). These findings are not completely consistent among studies, however. Lambert (1992), for instance, found small increases in abundance of about 10–20% for terrestrial, understory, and foliage-gleaning species after logging in Sabah. Substantial local increases in abundance have also been noted for generalist feeders that can supplement nectar and fruit resources with insects (Johns 1991, 1992; Lambert 1992; Thiollay 1992). The opening of the canopy often, though not always, increases the availability of nectar and fruits in early successional patches, in turn supporting more abundant populations of generalist feeders. The guild showing the most consistent responses to logging operations are the sallying insectivores, which almost universally experience a local reduction of 60% or more in logged-over areas (but see Johns 1991).

Apparent inconsistencies in results are common among

studies of bird populations in logged areas. In addition to the ubiquitous difficulties in generalizing among studies, the arbitrary nature of the division into feeding guilds (Thiollay 1992) and the wide variety and specificity of ecological requirements of many forest bird species make these studies particularly specific to location.

The data on mammals, too, indicate responses to logging ranging from withdrawal and local extirpation to significant increases in the abundance of some species (Wilson & Johns 1982; Shelton 1985). Some taxa, especially rodents and other small mammals, show declines in species diversity together with increases in overall abundance and dominance of a few cosmopolitan species (Isabirye-Basuta & Kasenene 1987; Stephenson 1993). Other studies have found little difference between logged and unlogged sites (Kikkawa & Dwyer 1992). A number of large browsing species, including elephant (*Loxodonta africana*), Baird's tapir (*Tapirus bairdii*), deer (*Cervus unicolor*, *Muntiacus muntjac*), Javan rhinoceros (*Rhinoceros sondaicus*), and bearded pig (*Sus barbatus*), are known to actively seek out disturbed forest areas for their quantities of grasses, palms, and young foliage (Johns 1983, 1985; Fragoso 1991; Struhsaker 1996), resulting in some cases in a synergistic negative effect on natural forest regeneration. Other large mammals, such as Sumatran rhinoceros (*Dicerorhinus sumatrensis*), Malay tapir (*Tapirus indicus*), and sun bear (*Helarctos malayanus*), avoid disturbed areas (Shelton 1985; Fragoso 1991).

More data are available on the responses of primates to logging than on any other mammal group, but consistent trends are still hard to pick out. Johns and Skorupa (1987) found that frugivorous Neotropical monkey species (*Chiropotes* spp., *Ateles paniscus*) will leave a logged-over area if their food trees have been extracted, whereas *Saguinus* spp., which eat both fruits and insects, survive well in logged areas and may increase in density as much as 10-fold. Generalist feeders (e.g., *Pithecia albicans*) do well in disturbed areas, and some *Callicebus* species actually prefer a secondary forest or crop mosaic to primary forest, except for *C. torquatus* (also a generalist feeder), which was shown to decrease by 70–100% in secondary forest. Many Old World primate species, especially frugivores (*Pongo pygmaeus*, *Pan troglodytes*), experience sharp declines in population density after logging, whereas folivores (*Colobus* spp., *Gorilla gorilla*) decline less or increase (Johns & Skorupa 1987). There are indications that birth rates in some primate species have declined in logged Malaysian forests (Johns & Skorupa 1987; Johns 1992), possibly because of changes in social and behavioral patterns. This observation indicates that some effects on wildlife may remain undetected for many years after logging, and it emphasizes the difficulty of predicting the reactions of animals with complex behavioral responses to an event such as logging.

The few studies of leaf-litter herpetofauna indicate that primary forest plots tend to harbor a greater diver-

sity, with lower abundance, of reptiles and amphibians than plots in secondary and regenerating forests of various types (Inger & Colwell 1977; Heinen 1992; Kikkawa & Dwyer 1992).

Butterflies and moths are clearly reduced in both species richness and abundance in logged forests as compared with primary forests (Holloway et al. 1992; Hill et al. 1995), and this is true despite the fact that both groups show increased richness and abundance in disturbed areas on a finer scale (Kremen 1992). Beetles, cockroaches, and millipedes increase significantly in both species richness and abundance after logging, whereas spiders, mites, scorpions, springtails, and termites all decrease (Nummeling & Borowiec 1991; Burghouts et al. 1992). Some groups, such as the Cassidinae beetles, include no species found in closed forest conditions. The increased presence of such groups in logged forest may be due to invasion by grassland species into the newly opened forest environment (Nummeling & Borowiec 1991). Ants generally seem to be reduced in terms of species diversity in secondary or regenerating forests (Burghouts et al. 1992; Roth et al. 1994), although they may remain abundant in these habitats (Kikkawa & Dwyer 1992). Although data on certain invertebrate taxa are increasing, there remains a critical deficiency of information on the impact of logging on invertebrates at the community level.

### Overall Trends

Overall, then, the pattern of change in tropical forest biodiversity following logging tends toward a local increase in the abundance and diversity of certain species. This increase is found primarily in the abundance and range of those species adapted to gap environments and disturbed habitats and of those able to use a variety of resources (Frumhoff 1995). At the same time there may be a regional decline in species richness due to the loss or shrinking geographic range of those species adapted to the relatively constant conditions of the forest interior and of those dependent upon a narrow range of resources. This decline will be detectable only by a comparison of indices of species diversity over time at the regional level. Such indices are generally lacking. In addition, there is a dearth of studies that examine the impact of forest management on ecosystem processes, particularly species interactions including mutualisms, below-ground processes, and the diversity of soil organisms, all of which are thought to play a long-term role in maintaining overall biodiversity (Daily 1997). Furthermore, at the intraspecific level the effects of natural forest management on genetic diversity remain unexplored (Namkoong et al. 1996).

There are three major difficulties in interpreting the results of past studies. First, differences in ecological conditions independent of logging events, differences in spatial and temporal scales examined, differences in

methodology, and differences in the characteristics of respective logging operations, make it difficult to predict precisely how timber harvests may affect biodiversity. In particular, the overall effects of logging are likely to vary with the size of the area harvested and the extent to which the area is embedded in a natural, undisturbed forest matrix (Boyle & Sayer 1995). Second, few of the studies have considered the synergistic effects of disturbance other than logging. In contemporary tropical landscapes, fragmentation and other forest habitat alteration including climate change may enhance any negative effects of logging on biodiversity. Furthermore, logging has generally been accompanied by increased incidence of hunting, fire, roads, and human occupation of logged forests (Uhl & Buschbacher 1985; Frumhoff 1995). Third, the sustainability of NFM cannot, in principle, be rigorously evaluated until at least three cycles of harvest are completed (Poore et al. 1989). The studies cited above were conducted in forests that have undergone just one or two cycles of extraction. It would be appropriate to keep in mind the remarks of Wyatt-Smith (1987), who pioneered several tropical forest management systems, that tropical forests under NFM are likely to become progressively more homogeneous in structure.

### Economic Viability of Natural Forest Management

It might be argued that almost all of a tropical forest's biodiversity could be conserved if the number of stems extracted could be kept to a strict minimum. As extraction becomes less intensive, however, per-tree damage levels rise, primarily because the extent of road building per tree extracted rises exponentially (Gullison & Hardner 1993; Boot & Gullison 1995). In some areas extraction by means of helicopter has been considered, but such methods have yet to prove cost effective (International Tropical Timber Organization 1994). In most areas at present, large reductions in harvesting intensity seem to reduce the economic viability of NFM systems. Already several reports indicate that, compared to other land uses, NFM yields poor financial returns (Goodland et al. 1991; Kishor & Constantino 1994). The latest such report from the International Tropical Timber Organization (1994) shows that economic gains from plantations and other land uses exceed those from NFM under a wide variety of conditions, especially when revenues from the first logging cycle are excluded from accounting. Yields from the first cut from primary forest are consistently larger than succeeding yields. Reports about the lack of economic viability stand in contrast to the optimistic notions about NFM often put forward by international donor agencies (International Tropical Timber Organization/Harvard Institute for International Development 1988; Sharma 1992; International Tropical Timber Organization 1994). The optimistic scenarios

rarely consider economic factors that the policy makers or shareholders in the land take into account when making decisions about land use.

The net biological productivity of intact tropical moist or dry forest, like other old-growth forests, is very low, approaching zero. Disturbance such as selective logging often promotes regeneration and raises productivity (Goodland et al. 1991). Nevertheless, limiting harvest to the increment grown since the last cut would provide only small yields. How yields translate into profits depends upon a number of economic factors. Decisions about alternative uses are based on (1) prevailing discount rates, which are influential in determining the attractiveness of one option in relation to another, (2) general disregard for externalities, and (3) national and international price structures, which depend upon tariffs, labor and transport costs, and mill efficiency.

The net present value of future revenues from natural forest management is likely to be low for small farmers in developing countries because of the high cost of borrowing (Kishor & Constantino 1994). As a result there is little incentive to opt for the steady and long-term gains that may accrue from NFM. Discount rates should be low and the net present value of future benefits should be high for many governments who own large forest estates, but public agencies have an extremely poor record of practicing sustainable NFM in most countries. Moreover, although forests in many areas are publicly owned, extraction is left to private concessionaires. These private enterprises, operating almost invariably on the basis of short-term leases, have little incentive for sustainable management or for concern with biodiversity (Poore et al. 1989).

Externalities, or social costs and values, are also likely to be disregarded by small landowners who alone cannot bear the costs of conserving biodiversity and maintaining ecosystem services. For lands under public ownership, externalities are not taken into account by policy makers. Moreover, many external benefits are widely dispersed, often beyond the bounds of the units managed for timber extraction. Sustainable NFM would be difficult to achieve without approaching equity in bearing the external costs.

National and international price structures are influenced by a host of policies at local and national levels. In most areas of the world, markets for tropical timber are still supplied largely by timber cut from primary forests or produced as a side-effect of clearing land for agriculture (Poore et al. 1989). These "forest mining" processes have the effect of depressing local timber prices and drastically lowering the perceived worth of forests. Moreover, many analysts have observed that log export bans tend to exacerbate this effect by protecting inefficient domestic processing industries from more intense competition and higher prices on the international market (Vincent 1992; Barbier 1995). Removal of the bans without adequate pro-

tection, however, would be likely to result in even greater forest overexploitation because the export profits on unprocessed logs would skyrocket (Kishor & Constantino 1996a, 1996b). "Stumpage" prices—prices paid by loggers per unit of timber extracted—are set administratively in many developing countries, and they almost always understate market stumpage value (Vincent 1995). This encourages use of old-growth primary forests and discourages investment in secondary and regenerating forests.

At the international level, some policies of the industrial world directly constrain and distort timber price structures in the developing world. Examples include high-leverage financing of investments from the developed world in developing-world timber and protectionism by developed nations against processed wood products. These kinds of policies heighten the disparity between pricing structures in the developing and the developed world, although the nature and extent of their influence remains the subject of debate (Myers 1997; Vincent & Panayotou 1997).

## Sustained Yield

The viability of NFM thus remains open to question on the basis both of ecology (maintenance of biodiversity) and economics. Its status as a means of obtaining a sustainable yield of timber is also still being questioned on silvicultural grounds. Trees are long-lived, with rotation cycles of 40–50 years for most NFM systems, and many decades if not centuries are required to determine if sustained yields are possible (Botkin & Talbot 1992). In theory it should be possible to harvest a certain fraction of primary productivity without undermining ecosystem structure and function, but in practice, as the history of NFM systems in the tropics suggests, the goal of sustained yield without degradation of the habitat is difficult to achieve. The definition of sustained yield implies that communities exist in a steady state, which we now know is not the case. It is important to note that the twin goals of sustainability and maintenance of biodiversity have been difficult to achieve even in structurally simple temperate-zone forests, and the lack of concern about biodiversity in forest management has been the major impetus for proposing new paradigms and models in management of temperate-zone forests (Aplet et al. 1993; Canadian Council of Forest Ministers 1995; Intergovernmental Seminar on Criteria and Indicators for Sustainable Forest Management (ISCI) 1996; Bouman & Brand 1997).

## Options

What are the options for conserving, managing, and using tropical forest resources? Much of the tropical timber in demand today is destined for use as particle

board, plywood, concrete forms, and paper (Goodland et al. 1991; Vincent 1992) and could be harvested from secondary forests. Logging in secondary forests is indeed increasing worldwide. During the last 30 years, the area of logged primary forest has doubled and that of logged secondary forest has increased by a factor of 4.5. Worldwide, however, primary forests still constitute by far the greatest area of forest exploitation, with 4.9 million ha being logged annually (World Resources Institute 1994). Although precise figures for the extent of secondary forests in the tropics do not exist, the same general trend is thought to prevail (Brown & Lugo 1990; Goodland et al. 1991).

Many secondary and regenerating forests are threatened with conversion to other land uses because they are close to the agricultural frontier and are of relatively easy access. Often lacking the large and valuable trees associated with old growth, tropical secondary forests tend to be overlooked as resources by private owners, the timber industry, and government agencies (Finegan 1992a; Del Amo & Ramos 1993; Solórzano 1995). These forests should be recognized as valuable resources which, if utilized, could help take pressure off dwindling primary forests. Some industry adjustments will be needed to accomplish efficient use of secondary forests. These include both adjustments in technical aspects—such as expansion of the list of commercially acceptable species and reduction of the minimum-diameter standards at sawmills—and in policy—such as an end to subsidies for competing land uses and stronger encouragement of reforestation efforts.

One impediment to the use of secondary forest resources is the fact that commercial markets are unaccustomed to many of the characteristic tree species. In reference to Central and South America, however, Finegan (1992b) describes the Neotropical secondary forest as relatively uniform from a biogeographical point of view. Richards (1996) also points out that tropical secondary forest tree species tend to be both wide-spread and regionally uniform in ecological characteristics. A commonly advanced concern about the management prospects of many tropical old-growth forests is that they may be too diverse and complex to permit conventional management on a sustainable basis (Rice et al. 1997). On the other hand, an ever-increasing number of secondary forest species is now in commercial use locally, and more could be (Budowski 1988; Wadsworth 1988; Brown & Lugo 1990). From an ecological perspective, the prospects for development of management systems appropriate to such forests are favorable.

Reduced economic returns from the decreased logging associated with NFM may be compensated for in some areas through the multiple use of forests—for example, through extraction of nontimber forest products (Panayotou & Ashton 1992) and ecotourism. Multiple use would also lower biodiversity, but it may prevent

the severe degradation that usually accompanies a high level of extraction. Degradation may be curtailed because of the greater involvement of local communities in management and greater equity in the distribution of benefits. But we know of no management system in the tropics that seeks explicitly to integrate the harvest of timber and nontimber forest products in the management plan, except for the joint forest management systems in India (Poffenberger 1990) that are restricted to regenerating forests on degraded lands and not primary forests. Moreover, we should also keep in mind that the flow of returns from the exploitation of nontimber products rarely compares in magnitude with the returns from timber harvests and rarely reaches the same social groups. Thus, the potential for direct trade-offs may be limited without substantial institutional and policy changes (Bawa & Gadgil 1997).

One of the main reasons why NFM systems employing decreased levels of logging are considered nonviable is the prevailing disregard for the external benefits that forests provide. These include ecosystem services, such as the maintenance of biodiversity. Substantial progress in the development of NFM systems could be achieved if the true benefits of forests were realized and the costs associated with these benefits were spread widely and reflected in the price of products harvested (Myers 1995). Unfortunately, there has been little progress so far in devising mechanisms that would allow the people living away from forests, both within and across national boundaries, to bear these costs.

"Green" certification systems have been proposed as one means of spreading the cost of sustainable forestry techniques and forest conservation, using the power of the market to do so. It is unclear, however, that such systems would have the desired effect even if they can be established quickly and on a wide enough scale. Depending on the particulars of the forest and the industry in question, current (unsustainable) logging patterns may be many times more profitable (as much as 500% according to one study) than more moderate, green alternatives (Rice et al. 1997). Consumers, on the other hand, are rarely willing to spend much more than a fraction (say, 10%) extra for certification. It is hard to see how such measures will contribute much to overcoming the "market and policy failures" permeating the tropical timber industry (Vincent & Panayotou 1997) before such time as the remaining forests have been essentially eliminated.

National and international organizations should enhance their efforts to reforest degraded lands with mixed species plantations of native industrial hardwoods. Rhetoric about forest plantations in the tropics aside, there has been little progress in this area during the last several years (see also Khoshoo 1996). Tropical forest plantations continue to remain largely monocultures of softwoods, in most cases exotic species, and in

many cases they are still being raised on lands recently cleared of primary forests. Intensive use of degraded forests with appropriate technical and managerial input can probably save a considerable amount of primary forest by deflecting demand.

Finally, it should be recognized that substantial preserved areas closed to exploitation must remain at the heart of any regional biodiversity conservation plan. Efforts to improve low-impact extraction methods, develop certification programs, and promote NFM must not be made at the expense of a focus on preserved areas. No amount of experimentation with management plans can substitute, from the biodiversity perspective, for protecting substantial areas of primary forest. Strengthening government agencies charged with protecting forest reserves (Honadle 1993) and promoting the development of locally based ecotourism should therefore be important goals of international agencies.

It is appropriate here to point out what is almost a truism, that reserve systems by themselves will also fail to maintain high levels of forest biodiversity in the long run. Human use must inevitably constitute a major component of any regional plan for forest management, so better (more sustainable) use is clearly preferable to worse (more destructive) use. For many forests, best-use procedures have yet to be developed. But we suggest that the development of better forest management systems will not in itself keep us on track toward the goal of biodiversity maintenance.

## Conclusion

There is some consensus today among researchers that natural forest management of most tropical forests is feasible from a purely technical point of view (Jonkers & Schmidt 1984; Schmidt 1987; Berner & Stadtmüller 1988; Buschbacher 1990; Colchester 1990; Kirmse et al. 1993; Bruenig 1996; Uhl et al. 1997). Most researchers agree that it is the economic, social, and political aspects of NFM that present decisive obstacles. The social conditions that would permit the technical possibilities to be realized—such as stronger national forestry sectors, more realistic national and international pricing and accounting systems, and sharing of the costs of externalized forest services—show few signs of becoming widespread within the next few decades.

Significant uncertainties remain about the effects on biodiversity of any level of exploitation of primary tropical forest. The extent to which NFM might be expected to conserve biodiversity depends on several factors, including the initial structure of the forest, the scale and intensity of operations in space and time, and the geographical configuration of managed forest areas within the matrix of undisturbed, primary forest. Based on the

above review of available data, logged forests can broadly be expected to lose substantial amounts of biodiversity over the long term. We must remember that compatibility between the two goals of economically viable NFM and conservation of biodiversity has been difficult to achieve even in structurally simple temperate-zone forests and with all the financial, technical, and managerial resources that forestry agencies in temperate-zone countries can muster.

For these reasons, the concept of NFM needs to be disentangled from that of biodiversity conservation. The expectation remains unsupported that we can manage primary or relatively undisturbed tropical forests in a manner both economically productive and compatible with the preservation of biodiversity. This should not be interpreted to mean that we see little value in the development of better methodologies for low-impact extraction. Forests will inevitably continue to be logged on a large scale, and NFM may contribute to the conservation of biodiversity in some tropical forests when management plans are implemented faithfully and extraction levels kept low (Uhl et al. 1997). Improved management procedures are needed, and they must be developed, if only to maintain some continuity of production levels in managed forests. This has been the stated goal of professional foresters at least since the nineteenth century and still is today (Bruenig 1996). But the history of NFM is largely one of unsustainability in the places where it has been practiced (Budowski 1988; Poore et al. 1989; Johnson & Cabarle 1993). Tropical forest management is not unique in this respect: resources throughout history have been overexploited (Repetto & Gillis 1988; Ludwig et al. 1993; McNeely 1994). The dynamic of overexploitation results less from technical ignorance than from social and economic constraints and pressures.

Natural forest management might best be viewed as a way to buy time, to fill some of the demand for wood products in the short term while exerting a minimum impact on biodiversity in the process. Among international donor agencies, stronger emphasis should be placed on the development of more-intensive uses of smaller areas of forest, especially secondary forest; the multiple use of forest; and the reforestation of degraded lands. NFM must not be counted on to eliminate the need for better protection of preserved areas, many of which are coming under increasing pressure from agriculture and development, as well as logging interests. Moreover, it is vital that mechanisms be devised for a more equitable distribution of the costs of conserving biodiversity than we have at present. These changes in emphasis will require major adjustments in the policies of national and international institutions and in the structure of the national and international tropical timber industries. Unless these changes and adjustments are made, we must expect to see continuing losses of biodiversity and degradation of tropical lands.

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## Literature Cited

- Aplet, G., N. Johnson, J. T. Olson, and V. A. Sample, editors. 1993. Defining sustainable forestry. Island Press, Washington, D.C.
- Barbier, E. B. 1995. The economics of forestry and conservation: economic values and policies. *Commonwealth Forestry Review* 74: 26-34.
- Baur, G. N. 1964. The ecological basis for rainforest management. United Nations Food and Agriculture Organization, Rome.
- Bawa, K. S., and M. Gadgil. 1997. Ecosystem services in subsistence economies and conservation of biodiversity. Pages 295-310 in G. Daily, editor, *Nature's services: societal dependence on natural ecosystems*. Island Press, Washington, D.C.
- Berner, P., and T. Stadtmüller. 1988. Naturnaher Waldbau in Bergwäldern der feuchten Tropen: Erfahrungen, Probleme und Perspektiven. *Schweizer Zürcher Forstwesen* 139:1031-1044.
- Boot, R. G. A., and R. E. Gullison. 1995. Approaches to developing sustainable extraction systems for tropical forest products. *Ecological Applications* 5:896-903.
- Botkin, D. B., and L. M. Talbot. 1992. Biological diversity and forests. Pages 47-74 in N. P. Sharma, editor. *Managing the world's forests*. Kendall/Hunt Publishing, Dubuque, Iowa.
- Bouman, O. T., and D. G. Brand. 1997. Sustainable forests: global challenges and local solutions. Food Products Press, Binghamton, New York.
- Boyle, T. J. B., and J. A. Sayer. 1995. Measuring, monitoring and conserving biodiversity in managed tropical forests. *Commonwealth Forestry Review* 74:20-25.
- Brown, S., and A. E. Lugo. 1990. Tropical secondary forests. *Journal of Tropical Ecology* 6:1-32.
- Bruenig, E. F. 1996. Conservation and management of tropical rainforests: an integrated approach to sustainability. CAB International, United Kingdom.
- Budowski, G. 1988. Is sustainable harvest possible in the tropics? *American Forests November/December*: 34-37, 79-81.
- Burghouts, T. B. A., G. Ernesting, G. Korthals, and T. deVries. 1992. Litterfall, leaf litter decomposition and litter invertebrates in primary and selectively logged dipterocarp forest in Sabah, Malaysia. *Philosophical Transactions of the Royal Society of London B* 335:407-416.
- Buschbacher, R. J. 1990. Ecological analysis of natural forest management in the humid tropics. Pages 59-79 in R. J. Goodland, editor. *The race to save the tropics*. Island Press, Washington, D.C.
- Canadian Council of Forest Ministers. 1995. Defining sustainable forest management: a Canadian approach to criteria and indicators. Canadian Forest Service, Ottawa.
- Cannon, C. H., D. R. Peart, M. Leighton, and K. Kartawinata. 1994. The structure of lowland rainforest after selective logging in West Kalimantan, Indonesia. *Forest Ecology and Management* 67:49-68.
- Center for International Forestry Research (CIFOR). 1993. Interna-

- tional forestry research: towards the 21st century. A provisional medium-term plan for CIFOR, 1994–1998. CIFOR, Bogor, Indonesia.
- Colchester, M. 1990. The ITTO: kill or cure for the rainforests? *The Ecologist* 20:166–173.
- Daily, G., editor. 1997. Nature's services: societal dependence on natural ecosystems. Island Press, Washington, D.C.
- Del Amo, R. S., and P. J. Ramos. 1993. Use and management of secondary vegetation in a humid-tropical area. *Agroforestry Systems* 21:27–42.
- Finegan, B. 1992a. The management potential of neotropical secondary lowland rain forest. *Forest Ecology and Management* 47:295–321.
- Finegan, B. 1992b. El potencial de manejo de los bosques húmedos secundarios neotropicales de las tierras bajas. Serie Técnica, Informe Técnico no. 188. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba, Costa Rica.
- Fragoso, J. M. 1991. The effect of selective logging on Baird's tapirs. Pages 295–304 in M. Mares and D. J. Schmidly, editors. Latin American mammalogy: history, biodiversity and conservation. University of Oklahoma Press, Norman.
- Frumhoff, P. 1995. Conserving wildlife in tropical forests managed for timber. *BioScience* 45:456–464.
- Ganzhorn, J. U., A. W. Ganzhorn, J. P. Abraham, L. Andriamananjara, and A. Ramananjato. 1990. The impact of selective logging on forest structure and tenrec populations in western Madagascar. *Oecologia* 84:126–133.
- Goodland, R. J., E. O. A. Asibey, J. C. Post, and M. B. Dyson, 1991. Tropical moist forest management: the urgency of transition to sustainability. Pages 486–515 in R. Costanza, editor. Ecological economics: the science and management of sustainability. Columbia University Press, New York.
- Gullison, R. E., and J. J. Hardner. 1993. The effects of road design and harvest intensity on forest damage caused by selective logging: empirical results and a simulation model from the Bosque Chimanes, Bolivia. *Forest Ecology and Management* 59:1–14.
- Hartshorn, G. S. 1995. Ecological basis for sustainable development in tropical forests. *Annual Review of Ecology and Systematics* 26: 155–175.
- Heinen, J. T. 1992. Comparisons of the leaf litter herpetofauna in abandoned cacao plantations and primary rain forest in Costa Rica: some implications for faunal restoration. *Biotropica* 24:431–439.
- Hill, J. K., K. C. Hamer, L. A. Lace, and W. M. T. Banham. 1995. Effects of selective logging on tropical forest butterflies on Buru, Indonesia. *Journal of Applied Ecology* 32:754–760.
- Holloway, J. D., A. H. Kirk-Spriggs, and C. Vunkhen. 1992. The response of some rain forest insect groups to logging and conversion to plantation. *Philosophical Transactions of the Royal Society of London B* 335:425–436.
- Honadle, G. 1993. Institutional constraints on sustainable resource use: lessons from the tropics showing that resource overexploitation is not just an attitude problem and conservation education is not enough. Pages 90–119 in G. Aplet, N. Johnson, J. T. Olson, and V. A. Sample, editors. Defining sustainable forestry. Island Press, Washington, D.C.
- Intergovernmental seminar on criteria and indicators for sustainable forest management. (ISCI). 1996. Summary report. 19–22 August, Helsinki. Ministry of Agriculture and Forestry, Helsinki.
- Inger, R., and R. Colwell. 1977. Organization of contiguous communities of amphibians and reptiles in Thailand. *Ecological Monographs* 47:229–254.
- International Tropical Timber Organization. 1994. The economic case for natural forest management. I. Main report. Forest Research Institute of Malaysia, Kuala Lumpur.
- International Tropical Timber Organization/Harvard Institute for International Development. 1988. The case for multi-use management of tropical hardwood forests. Cambridge, Massachusetts.
- Isabirye-Basuta, G., and J. M. Kasenene. 1987. Small rodent populations in selectively felled and mature tracts of Kibale Forest, Uganda. *Biotropica* 19:260–266.
- Janzen, D. H. 1988. Tropical dry forests: the most endangered tropical ecosystem. Pages 130–137 in E. O. Wilson, editor. *Biodiversity*. National Academy Press, Washington, D.C.
- Johns, A. D. 1983. Tropical forest primates and logging—can they co-exist? *Oryx* 17:114–118.
- Johns, A. D. 1985. Effects of selective logging on the behavioral ecology of West Malaysian primates. *Ecology* 67:684–694.
- Johns, A. D. 1988. Effects of "selective" timber extraction on rain forest structure and composition and some consequences for frugivores and folivores. *Biotropica* 20:31–37.
- Johns, A. D. 1991. Responses of Amazonian rain forest birds to habitat modification. *Journal of Tropical Ecology* 7:417–437.
- Johns, A. D. 1992. Vertebrate responses to selective logging: implications for the design of logging systems. *Philosophical Transactions of the Royal Society of London B* 335:437–442.
- Johns, A. D., and J. P. Skorupa. 1987. Responses of rain-forest primates to habitat disturbance: a review. *International Journal of Primatology* 8:157–191.
- Johnson, N., and B. Cabarle. 1993. Surviving the cut. World Resources Institute, Washington, D.C.
- Jonkers, W. B. J., and P. Schmidt. 1984. Ecology and timber production in tropical rainforest in Suriname. *Interciencia* 9:290–298.
- Khoshoo, T. N. 1996. Making forestry sustainable in India. *Current Science* 70:205–214.
- Kikkawa, J., and P. D. Dwyer. 1992. Use of scattered resources in rain forest of humid tropical lowlands. *Biotropica* 24:293–308.
- Kirmse, R. D., L. Constantino, and G. M. Guess. 1993. Prospects for improved management of natural forests in Latin America. LATEN dissemination note 9. The World Bank, Washington, D.C.
- Kishor, N. M., and L. Constantino. 1994. Sustainable forestry: can it compete? *Finance and Development* 31:36–39.
- Kishor, N. M., and L. Constantino. 1996a. Voting for economic policy reform: efficiency gains and redistributive impacts of removing the log export ban in Costa Rica. LATEN dissemination note 15. The World Bank, Washington, D.C.
- Kishor, N. M., and L. Constantino. 1996b. Trade policies and the forest sector: lessons from country experiences. LATEN dissemination note 16. The World Bank, Washington, D.C.
- Kremen, C. 1992. Assessing the indicator properties of species assemblages for natural areas monitoring. *Ecological Applications* 2:203–217.
- Lambert, F. R. 1992. The consequences of selective logging for Bornean lowland forest birds. *Philosophical Transactions of the Royal Society of London B* 335:443–457.
- Lamprecht, H. 1989. Silviculture in the tropics. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Eschborn, Germany.
- Landy, J. P. 1995. Sustainable forest management: lessons of history and recent developments. *Unasylva* 182:38–45.
- Lawton, J. 1997. The role of species in ecosystems: aspects of ecological complexity and biological diversity. Pages 215–228 in H. Abe, S. Levin, and A. Higashi, editors. *Biodiversity: an ecological perspective*. Springer Verlag, New York.
- Lele, S. 1991. Sustainable development: a critical review. *World Development* 19:607–621.
- Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation: lessons from history. *Science* 260:17–36.
- Lugo, A. E. 1995. Management of tropical biodiversity. *Ecological Applications* 5:956–961.
- Malmer, H., and H. Grip. 1990. Soil disturbance and loss of infiltrability caused by mechanical and manual extraction of tropical rainforest in Sabah, Malaysia. *Forest Ecology and Management* 38:1–12.
- McNeely, J. A. 1994. Lessons from the past: forests and biodiversity. *Biodiversity and Conservation* 3:3–20.
- Myers, N. 1995. The world's forests: need for a policy appraisal. *Science* 268:823–824.
- Myers, N. 1997. Consumption: challenge to sustainable development or distraction? *Science* 276:53–57.

- Namkoong, G., T. Boyle, H.-R. Gregorius, H. Joly, O. Savolainen, W. Ratnam, and A. Young. 1996. Testing criteria and indicators for assessing the sustainability of forest management: genetic criteria and indicators. Working paper no. 10. Center for International Forestry Research, Jakarta, Indonesia.
- Nummelin, M., and L. Borowiec. 1991. Cassidinae beetles of the Kibale Forest, western Uganda; comparison between virgin and unmanaged forests. *African Journal of Ecology* 29:10-17.
- Okali, D. U. U., and B. A. Ola-Adams. 1987. Tree population changes in treated rain forest at Omo Forest Reserve, south-western Nigeria. *Journal of Tropical Ecology* 3:291-313.
- Panayotou, T., and P. Ashton. 1992. Not by timber alone: economics and ecology for sustaining tropical forests. Island Press, Washington, D.C.
- Poffenberger, M. 1990. Joint management for forest lands: experiences from south Asia. Ford Foundation, New Delhi, India.
- Pomeroy, M. 1996. Fifty-four years of change in the stand structure and species composition of rain forest in the Western Ghats of India. Ph.D. thesis. Boston University, Boston.
- Poore, D., P. Burgess, J. Palmer, S. Rietbergen, and T. Synnot. 1989. No timber without trees: a study for ITTO. Earthscan Publications, London.
- Primack, R. B., and H. S. Lee. 1991. Population dynamics of pioneer (*Macaranga*) trees and understorey (*Mallotus*) trees (*Euphorbiaceae*) in primary and selectively logged Bornean rain forests. *Journal of Tropical Ecology* 7:439-458.
- Quiros, D., and B. Finegan. 1994. Manejo sustentable de un bosque natural en Costa Rica. Informe tecnico no. 225. Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)/Cooperación Suiza al Desarrollo (COSUDE). Turrialba, Costa Rica.
- Repetto, R., and M. Gillis, editors. 1988. Public policies and the misuse of forest resources (a study for World Resource Institute). Cambridge University Press, Cambridge, United Kingdom.
- Rice, R. E., R. E. Gullison, and J. W. Reid. 1997. Can sustainable management save tropical forests? *Scientific American* April:44-49.
- Richards, P. W. 1996. The tropical rainforest: an ecological study. 2nd edition. Cambridge University Press, Cambridge, United Kingdom.
- Roth, D. S., I. Perfecto, and B. Rathcke. 1994. The effects of management systems on ground-foraging ant diversity in Costa Rica. *Ecological Applications* 4:423-436.
- Sanchez-Azofeifa, A. 1996. Assessing land use/cover change in Costa Rica. PhD. dissertation. Earth Sciences, University of New Hampshire, Durham.
- Schmidt, R. 1987. Tropical rain forest management. *Unasylva* 156:2-17.
- Sharma, N. P., editor. 1992. Managing the world's forests. Kendall/Hunt, Dubuque, Iowa.
- Shelton, N. 1985. Logging versus the natural habitat in the survival of tropical forests. *Ambio* 14:39-41.
- Solórzano, R. 1995. Breve diagnóstico y soluciones de corto plazo al sector forestal nacional. Centro Científico Tropical, San Jose, Costa Rica.
- Stephenson, P. J. 1993. The small mammal fauna of Réserve Spéciale d'Analamazaotra, Madagascar: the effects of human disturbance on endemic species diversity. *Biodiversity and Conservation* 2:603-615.
- Struhsaker, T. T. 1996. Elephants, selective logging and forest regeneration in the Kibale Forest, Uganda. *Journal of Tropical Ecology* 12: 45-64.
- Thiollay, J.-M. 1992. Influence of selective logging on bird species diversity in a Guianan rain forest. *Conservation Biology* 6:47-60.
- Tilman, D. 1997. Biodiversity and ecosystem functioning. Pages 93-112 in G. Daily, editor. *Nature's services: societal dependence on natural ecosystems*. Island Press, Washington, D.C.
- Uhl, C., and R. Buschbacher. 1985. A disturbing synergism between cattle ranch burning practices and selective tree harvesting in the eastern Amazon. *Biotropica* 17:265-268.
- Uhl, C., and I. C. G. Vieira. 1989. Ecological impacts of selective logging in the Brazilian Amazon: a case study from the Paragominas region of the state of Pará. *Biotropica* 21:98-106.
- Uhl, C., P. Barreto, A. Veríssimo, E. Vidal, P. Amaral, A. C. Barros, C. Souza, Jr., J. Johns, and J. Gerwing. 1997. Natural resource management in the Brazilian Amazon. *BioScience* 47:160-168.
- United Nations Food and Agriculture Organization. 1993. The challenge of sustainable forest management. What future for the world's forests? Rome.
- United Nations Food and Agriculture Organization. 1995. Forest resources assessment 1990. FAO forestry series 24. Rome.
- United Nations Food and Agriculture Organization/United Nations Environmental Programme. 1981. Tropical forest resources assessment project. Rome.
- Vincent, J. 1992. The tropical timber trade and sustainable development. *Science* 256:1651-1655.
- Vincent, J. 1995. Timber trade, economics, and tropical forest management. Yale University Press, New Haven.
- Vincent, J., and T. Panayotou. 1997. Consumption: challenge to sustainable development or distraction? *Science* 276:53-57.
- Wadsworth, F. H. 1988. Finding forestry alternatives. *American Forests November/December*:36.
- Wilson, W. L., and A. D. Johns. 1982. Diversity and abundance of selected animal species in undisturbed forest, selectively logged forest and plantations in East Kalimantan, Indonesia. *Biological Conservation* 24:205-218.
- World Resources Institute. 1991. Accounts overdue: natural resource depreciation in Costa Rica. World Resources Institute, Washington D.C., in collaboration with the Tropical Science Center, San Jose, Costa Rica.
- World Resources Institute. 1994. World resources 1994-1995. World Resources Institute, Washington D.C., in collaboration with the United Nations Environmental Programme and the United Nations Development Programme. Oxford University Press, Cambridge, United Kingdom.
- Wyatt-Smith, J. 1987. Natural management of tropical forests, problems and prospects. Pages 6-22 in F. Mergen and J. Vincent, editors. *The natural management of tropical forests*. Yale University Press, New Haven, Connecticut.

