Essay

Beyond Reaping the First Harvest: Management Objectives for Timber Production in the Brazilian Amazon

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Abstract: *Millions of hectares of future timber concessions are slated to be implemented within large public forests under the forest law passed in 2006 by the Brazilian Congress. Additional millions of hectares of large, privately owned forests and smaller areas of community forests are certified as well managed by the Forest Stewardship Council, based on certification standards that will be reviewed in 2007. Forest size and ownership are two key factors that influence management objectives and the capacity of forest managers to achieve them. Current best ecological practices for timber production from Brazil's native Amazon forests are limited to reduced-impact logging (RIL) systems that minimize the environmental impacts of harvest operations and that obey legal restrictions regarding minimum diameters, rare species, retention of seed trees, maximum logging intensity, preservation of riparian buffers, fire protection, and wildlife conservation. Compared with conventional, predatory harvesting that constitutes >90% of the region's timber production, RIL dramatically reduces logging damage and helps maintain forest cover and the presence of rare tree species, but current RIL guidelines do not assure that the volume of timber removed can be sustained in future harvests. We believe it is counterproductive to expect smallholders to subscribe to additional harvest limitations beyond RIL, that larger private forested landholdings managed for timber production should be sustainable with respect to the total volume of timber harvested per unit area per cutting cycle, and that large public forests should sustain volume production of individual harvested species. These additional requirements would improve the ecological sustainability of forest management and help create a stable forest-based sector of the region's economy, but would involve costs associated with lengthened cutting cycles, reduced harvest intensities, and/or postharvest silviculture to promote adequate growth and regeneration.*

Keywords: forest management, reduced-impact logging, sustainability, sustained yield

Más Allá de la Primera Cosecha: Objetivos de Manejo para la Producción de Madera en la Amazonía Brasileña

Resumen: *Bajo la nueva ley forestal aprobada en 2006 por el Congreso Brasileño, millones de hectáreas de bosques públicos están destinadas a constituir futuras concesiones madereras. Millones de hectáreas adicionales de extensos bosques privados y áreas reducidas de bosques comunitarios están certificadas por el Forest Stewardship Council por su buen manejo, con base en estándares de certificación que serán revisados en 2007. La extensión y tenencia del bosque son dos factores clave que influyen en los objetivos de manejo y en la capacidad de los manejadores para alcanzarlos. Las mejores prácticas ecológicas actuales para la producción de madera en los bosques de la Amazonía Brasileña están limitadas a sistemas de tala de impacto reducido (TIR) que minimizan los impactos ambientales de las operaciones de cosecha y que obedecen*

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restricciones legales en relación con los diámetros mínimos, las especies raras, la retención de árboles semilla, la máxima intensidad de tala, la preservación de amortiguamientos ribereños, la protección del fuego y la conservación de vida silvestre. En comparación con la cosecha convencional, depredadora, mediante la cual se obtiene >90% de la producción de madera en la región, la TIR dramáticamente reduce el daño y ayuda a mantener la cobertura del bosque y la presencia de especies de árboles raras, pero los actuales lineamientos de TIR no aseguran que el volumen de madera removida pueda ser sostenido en futuras cosechas. Consideramos que es contraproducente esperar que los pequeños propietarios suscriban límites a la cosecha más allá de la TIR; que los bosques privados manejados para la producción de madera debieran ser sustentables respecto al volumen total de madera cosechada por unidad de área por ciclo de corte; y que los bosques públicos deberían sustentar el volumen de producción de especies individuales. Estos requerimientos adicionales mejorarían la sustentabilidad ecológica del manejo de bosques y ayudaría a crear un sector forestal estable en la economía regional, pero implicarían costos asociados con la prolongación de los ciclos de corte, la reducción de las intensidades de cosecha y/o la silvicultura postcosecha para promover el crecimiento adecuado y la regeneración.

Palabras Clave: manejo de bosques, producción sostenida, sustentabilidad, tala de impacto reducido

Introduction

Proponents of managing tropical forests for timber production argue that doing so will conserve forests and provide significant financial returns to their public and private owners. Opponents argue that timber production inevitably leads to forest degradation and that, from a financial perspective, predatory logging and subsequent conversion from forest to agricultural use, including pasture, will always outcompete forest management (Pearce et al. 2003). This debate is particularly pronounced in the Brazilian Amazon because of the rapid and mostly illegal expansion of the logging industry and its undeniable role in forest degradation and deforestation on the one hand (e.g., Nepstad et al. 1999; Asner et al. 2005, 2006) and efforts by the Brazilian government to control that expansion through the establishment of a new public forest law and the suspension of suspect harvesting permits on the other (Lei 11284/2006; MMA 2006).

In the Amazon basin actual management of native upland forests for commercial timber production (as opposed to a depletion mode of timber harvesting) has a short history, such that there is no experience beyond the first harvest. The varied objectives of the region's forest landowners, beyond that first harvest, have not been the subject of much systematic discussion in the literature. We aim to initiate that discussion here in the hope that it may lead to policy measures that adequately address disparities in management and conservation potential among forestlands of vastly different sizes and ownerships.

Decades of predatory and haphazard selective logging have degraded large areas of forest throughout the Brazilian Amazon (Cochrane et al. 1999; Uhl & Nepstad 2000; Gerwing 2002) and continue to characterize >90% of the region's timber production. One positive response to this forest degradation was the development of improved harvest planning and operations that collectively are referred to as reduced-impact logging ([RIL]; e.g., Hendrison 1990; Uhl et al. 1997; Putz et al. 2001). Recent analyses show that under certain circumstances, in addition to reducing environmental damage, RIL may increase financial returns from timber harvesting (e.g., on relatively flat terrain in the eastern Amazon; Barreto et al. 1998; Boltz et al. 2001; Holmes et al. 2002), but under other circumstances, the financial impact of RIL is negative (e.g., on steep slopes in Southeast Asia; Enters et al. 2002).

Reduced-impact logging is increasing in popularity in the region and are required for third-party certification of forest management, a process of independent verification that best practices are being implemented. The number of properties and the number of hectares of forest certified by the Forest Stewardship Council (FSC) in the Brazilian Amazon have increased substantially over the past 5 years, for both industry- and community-managed forestlands, although the latter constitute an extremely small proportion of the total area certified for timber production in the region (Fig. 1). Industry interest in certification is driven by desire for access to European markets that require it and/or provide a significant premium for certified products. Certification of community forests is constrained by the direct and indirect costs of becoming certified and the limited access of small and immature community enterprises to relevant markets. Community forest certification generally occurs only with substantial and prolonged input by nongovernmental organizations (Bass et al. 2001; Molnar 2003).

Recently a number of authors have pointed out that although RIL represents a major improvement over conventional, predatory practices, it is merely a harvest system that minimizes environmental and structural damage (e.g., Fredericksen & Putz 2003; Sist et al. 2003; Grogan et al. 2006). In the Brazilian Amazon, for example, RIL is composed of a set of preharvest and harvest best practices (e.g., 100% inventory of trees to be harvested, stand mapping, preharvest cutting of vines on trees to be

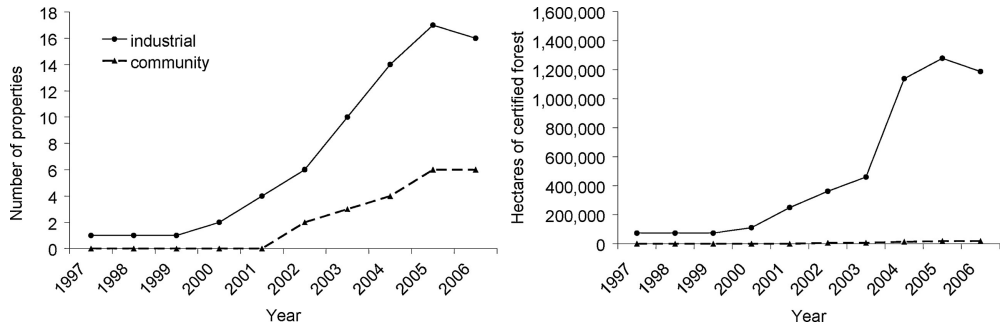

Figure 1. Number of FSC-certified industrial and community forest properties and the area of forest certified for timber production in the Brazilian Amazon (FSC 2006; Rainforest Alliance 2006; SCS 2006; SGS 2006). Decline in certification from 2005 to 2006 may be partly explained by a temporary moratorium on all annual harvest authorizations. Not included here are four community areas certified for nontimber forest production, including 1.5 million ha of Kayapo indigenous lands certified for Brazil-nut production.

harvested, road and skid-trail planning, directional felling, fire protection, wildlife conservation) imposed on a selective extraction regime that is legally determined on the basis of minimum diameters, a restriction on logging extremely rare species, minimum seed-tree requirements for harvested species (10% of commercial size individuals), preservation of riparian buffers, and a maximum logging intensity currently set at 30 m^3/ha (e.g., Uhl et al. 1997; Schulze et al. 2005; Grogan et al. 2006; Instrução Normativa 05/2006). As such, there is no guarantee that harvest volumes will be sustained over time or that other forest values will be maintained (Putz & Viana 1996; Fredericksen et al. 2003; Phillips et al. 2004).

At present there appears to be widespread agreement among tropical foresters and tropical forestry researchers that RIL is a critical first step in the development of management practices for naturally regenerated tropical forests (e.g., Barreto et al. 1998; Alder & Silva 2000; Putz & Fredericksen 2004). There is also an emerging concern that RIL alone may often be insufficient for achieving management objectives (e.g., Wadsworth 2001; Fredericksen et al. 2003; Putz & Fredericksen 2004). Nevertheless, there seems to be much uncertainty regarding what would be sufficient (Fredericksen & Putz 2003; Sist et al. 2003; Grogan et al. 2006). Furthermore, although most forest landowners view the first harvest as an opportunity to capture the financial value accrued by saleable trees, their land-management objectives beyond the first harvest range from converting that forest land to other productive uses from farming or cattle ranching, to sustaining the production of timber over the long term, to maintaining values as abstract as biodiversity.

In the Brazilian Amazon the uncertainty about what steps in addition to RIL are needed to achieve differing management objectives is particularly problematic now for at least four reasons. First, the public forest law recently passed by the Brazilian Congress calls for implementation of timber concessions over large areas of public forest land and mandates that those concessions be managed sustainably (Lei 11284/2006). What sustainable management means and how to do it are unresolved. Second, as the number of FSC-certified properties and the area of certified forestland increases in the region, certification of sustainable forest management appropriately comes under greater scrutiny. In practice, FSC certification appears to equate SFM with RIL, but certification standards will be reviewed in 2007. Third, community and smallholder timber-management projects are increasingly promoted as a forest-based alternative for rural development, and there is a growing debate about whether they should be held to the same regulatory and certification standards for SFM as large private or public landholders. Fourth, recent revision of forest management regulations in Brazil differentiates between mechanized and nonmechanized/low intensity harvesting operations, requiring a 25- to 35-year cutting cycle with a maximum logging intensity of 30 m^3/ha from the former, and a 10-year cutting cycle with a maximum logging intensity of 10 m^3/ha from the latter (Instrução Normativa 05/2006).

Much of the uncertainty about what is needed to achieve forest-management objectives is surely due to gaps in our understanding of stand and population dynamics within Amazonian forests and their response to RIL harvests (Martini et al. 1994; Putz & Viana 1996; Grogan et al. 2006). Nevertheless, a reasonably consistent set of observations suggest that following RIL tree mortality and growth both increase relative to unlogged forest and that the increase in mortality is less than that associated with conventional, predatory selective logging, whereas the increase in stand-level growth is greater (e.g., Silva et al. 1995; de Graaf et al. 1999; Vidal 2004). Nonetheless, there is great uncertainty regarding the sustainability of timber yields, particularly when initial harvest volumes are high relative to the forest's annual increment and when projected cutting cycles are short ($\leq$35 years). Within the Amazon Basin, we are unaware of any example of a second harvest following the completion of a projected cutting cycle that would allow one to evaluate

that uncertainty, although examples of unplanned reentry logging abound, and these tend to progressively degrade the harvested stands. Additionally, some commercially important timber species successfully regenerate in the aftermath of substantial disturbances of the sort that RIL practices deliberately prevent while exhibiting little to no regeneration following RIL (Jennings et al. 2001; Fredericksen & Putz 2003).

Differences in species population structures and intrinsic growth rates suggest that sustaining timber yields of many species would almost certainly require some combination of lower initial harvest volumes, longer cutting cycles, and postharvest silviculture (Wadsworth 2001; Wadsworth & Zweede 2006). Some researchers suggest that production volume can be sustained because species that are now less merchantable will increase in value as stocks of the current major commercial species are depleted (Alder & Silva 2000; Keller et al. 2004). Others are less sanguine about the economic prospects and the ecological consequences of that scenario (Phillips et al. 2004).

Some of those particular issues have been highlighted elsewhere (e.g., Schulze et al. 2005; Grogan et al. 2006). Here we discuss another fundamental source of uncertainty that has received less attention, namely the varied objectives of managing Amazonian forests beyond the first harvest. We suggest that these objectives vary in ways that are partly systematic and partly idiosyncratic. We treat what we consider to be the most basic systematic considerations: the size and ownership of the forest-management unit.

What differing requirements should be applied across size and ownership gradients, and the thresholds for their application, should be a matter of debate among stakeholders ranging from individual landowners to communities, logging companies, government agencies, nongovernmental organizations, and the larger civil society that may reasonably expect to benefit from the management of public forestlands. We highlight the size and ownership issues because we believe they should play an important role in these debates, and up to now they have not been parsed for analysis in anything approaching a systematic fashion. The specific proposals we make are intended to stimulate that debate, and we know that they neither are nor should be the final word on these matters.

Influence of Size and Ownership on Forest-Management Objectives

Size and ownership are critical parameters for forest management. Indeed, it may be impossible to manage smaller landholdings for sustained production of timber at the species level in species-diverse forests where many commercial species exist at low densities and/or in clumped distributions. This is especially true when some of those species have less than optimal size distributions, as is often the case, and where regeneration occurs sporadically—often under relatively rare environmental conditions (Fig. 2; Schulze et al. 2005). Under these circumstances, management that takes population and stand dynamics into account requires large areas.

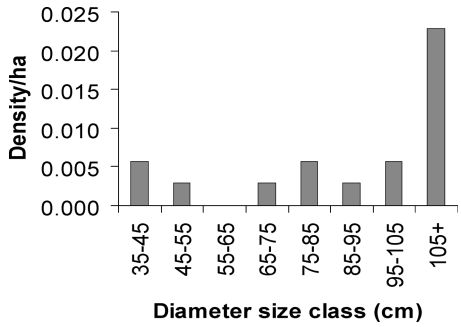

Figure 2. Adult diameter distributions of Tabebuia impetiginosa *(ipê) in 700 ha sampled at a site in the eastern Amazon (*n = *34 individuals > 35 cm diameter).*

Ownership status also influences the objectives of forest management. On the one hand, private owners, whether they are individuals or corporations, may be expected to manage primarily for private benefits. They may be regulated, formally or informally, to limit the damage their activities may do to public values, but we do not expect them to manage primarily in the public interest, even in FSC-certified forests in which additional private benefits are expected to derive from explicit consideration of public values. On the other hand, we do expect the managers of public forests to prioritize the public interest. We also recognize that private forest lands are transferable (i.e., they can be bought and sold) and almost always may be legally deforested, at least in part. Although formally approved forest-management plans are legally binding on future owners there has been no analysis of compliance with that requirement. In contrast ownership of public forests is unlikely to be transferable, and they are rarely intended for liquidation.

Within the Brazilian Amazon, there exists a continuum of size and ownership of forested landholdings. Under current best practices, forest management for timber on landholdings of any size or ownership aims to convert as much of the accumulated stock of merchantable timber into revenue as is legally permissible and to reduce the environmental impact of harvesting activities by following RIL practices. Beyond the first harvest, current legal requirements and RIL practices are intended to achieve the important objective of maintaining forest cover and the presence of the tree species that were in the stand prior to the harvest. Meeting this objective is clearly a necessary but insufficient condition for sustaining timber yields, a common production goal in forest management. We suggest that, on certain kinds of properties, the stepwise

Table 1. Forest-management objectives and practices proposed for application to landholdings of different sizes and ownerships in the Brazilian Amazon.

Objective	*Practices*	*Applies to*
Maintain forest cover and species presence	respect legal limits on riparian buffers, harvest volume, seed-tree designation, and rare species employ reduced-impact logging practices, including inventory, stand mapping, preharvest vine cutting, road and skid-trail planning, directional felling	all public and private land
Sustain total volume production of currently commercial species	adjust cutting cycles and harvest intensity based on stand-specific projection of commercial species volume accumulation control annual harvest area to allow completion of harvest rotation as needed, use postharvest silvicultural prescriptions (liberation thinning, site preparation for regeneration, vine cutting, enrichment planting) to promote growth and regeneration adequate for sustained volume production at desired cutting cycle	all public and private land >3,000 ha
Sustain volume production of each individual harvested species	adjust cutting cycles, harvest intensity, minimum diameters, and postharvest silvicultural prescriptions based on species-specific projections of volume accumulation	all public forests >10,000 ha

addition of two other objectives would greatly improve the prospects for sustainability (Table 1).

First, on larger landholdings (>3000 ha), forest management for timber should aim to sustain the total volume production of commercial species in subsequent harvests. Second, on public lands, forests managed for timber should have the additional objective of sustaining the volume production of the individual harvested species (Table 1). We recognize that many other objectives could be added, particularly with respect to nontimber forest values and that sustaining timber yields does not by itself constitute sustainable forest management, but where timber harvesting occurs, sustaining yields is a basic precept of sustainable forest management.

Constraints on Timber Management in Small Private Landholdings

At one end of the size-by-ownership continuum are small private landholdings. Typical examples include 100-ha properties within which, under the current terms of the legal reserve provision of the Brazilian Forest Code (Lei 4771/1965, Artigo 16, inciso I), at least 80 ha must be maintained under forest cover. There are tens of thousands of landholdings of this type in the region (Lima et al. 2006). Many small landowners routinely violate the legal reserve, and there is no financial incentive for small landowners to manage their forests. A recent pilot initiative shows some promise for neighboring landowners to jointly contract harvesting rights in an innovative arrangement with a small logging company that conforms to RIL practices (Lima et al. 2006; Nepstad et al. 2004*a, b*). Nonetheless, few small landowners concern themselves with sustainability of timber production in any guise and largely view the selective harvest as a one-time extraction event (Menton et al., unpublished data). They are most likely to invest earned returns on timber harvesting in economic activities on the 20% of their land that they are permitted to clear. Often this means purchasing cattle, and cattle ranching is the land use most closely tied to increased deforestation (Kaimowitz et al. 2004).

Even the most basic objective of maintaining forest cover on these small private landholdings is often a major challenge. They are prone to future haphazard reentry logging, ground fires escaped from adjacent cleared land, and piecemeal clearing as landowners seek to increase the productive agricultural area of their properties. Given their limited financial means, their land-use objectives, and the rather severe restrictions on the use of their properties, it may be both unreasonable and counterproductive to impose additional standards beyond current RIL practices on these landholders at this time. At present, postharvest monitoring of these properties is a major challenge to ensure that road and skid-trail infrastructure installed for a legal harvest are not subsequently used for clandestine purposes (Asner et al. 2002; de Wasseige & Defourny 2004; Souza & Roberts 2005).

To some extent Brazilian legislation has recognized the challenges small landowners face in complying with forest-management regulations through amendments to the basic forest code passed in 1965. For example, smallholders (defined as owning <500 ha or communities managing <500 ha/year) can submit simplified management plans that omit many of the technical details required of larger landowners (Instrução Normativa 05/1998). Private landholdings of this size encompass over 95% of the rural properties in the Brazilian Amazon and account for approximately 25 million ha (IBGE 1996) and 28% of the harvested timber volume (Lentini et al. 2005). Low-intensity/nonmechanized operations are authorized to harvest 10 m^3/ha every 10 years, and have more streamlined guidelines for management plans than do mechanized operations (Instrução Normativa 05/2006).

Management Opportunities in Large Public Forests

At the other end of the continuum are large public forests. A typical example would be a national forest, many of which are hundreds of thousands of hectares. The Brazilian national forest system is expanding, especially in the Amazon, and the expectation is that over the next decade, the system will include roughly 13 million ha (Magnusson 2002; Veríssimo et al. 2002). A new public forest law has recently been approved by the Brazilian Congress and, among its many provisions, it includes the development of a concession system for logging on these public lands (Lei 11284/2006). The new law and the national forest program that preceded it are explicit about sustainable management of those public resources. Although there is a distinct lack of specificity regarding what sustainable management actually means, it is reasonably clear that criteria for such management should not be limited to timber production and should consider economic, social, and environmental costs and benefits. We suggest that silvicultural objectives should attain the highest standard of managing public forests for the public good in perpetuity, and that where timber production is to occur on large public forests, consideration should be given to sustaining yields at the species level to avoid degradation of a public resource. Within the proposed concession system, meeting that objective could be a condition for a successful bid on a concession contract and for maintaining concession rights over time.

This focus on sustaining yields of individual species is particularly important because populations of many of the premier timber species in Amazonia are strongly weighted toward large, presumably very old, individuals (Fig. 2). Age estimates of certain canopy emergents in Amazonia have been as high as 1200 years (Chambers et al. 1998). A first timber harvest is therefore capitalizing on centuries of biomass accumulation.

Tree populations in which smaller, presumably younger, individuals do not vastly outnumber large individuals, may be associated with sporadic recruitment and relatively rapid transitions among size classes (Condit et al. 1998). Most of the species that display a flat or right-skewed diameter distribution pattern are light demanding, at least as seedlings and young saplings (Grogan 2001; Jennings et al. 2001; Schulze 2003). Large disturbance events (e.g., windbursts, fires, flooding) may create the conditions for regeneration of these species, and current aggregations of large adults may represent cohorts established after some past canopy disturbance (e.g., Snook 1996; Gullison et al. 1996; Fredericksen & Putz 2003). Populations with this structure present management challenges because timber harvests remove the vast majority of standing adult stems. Absent a large pool of submerchantable stems, recovery of harvestable biomass of any given species will be quite limited. This is especially true for species that are characterized by slow growth, such as *Tabebuia impetiginosa*, locally known as ipê (Schulze et al. 2005).

Sustaining timber yields of species like ipê depends on regeneration and recruitment success following the first harvest and on cutting cycles compatible with recruitment rates. Seedlings established much before logging occurs have a low probability of surviving long enough to exploit the patchy canopy openings created by the harvest. Variability in seed production, limited dispersal distances, short seed viability and low densities of seed-producing trees restrict the potential successful colonization of logging gaps by seeds (Schulze 2003). Once established in gaps, seedling growth is slow relative to pioneer species that typically dominate logging gaps and form dense canopy layers within 4-5 years (Fig. 3). Given seedling densities, growth rates, and mortality in logging gaps, replacement of harvested adults through natural regeneration in logged stands is likely to require a century, if it happens at all.

In the case of ipê and high-value timber species with similar population dynamics (e.g., *Swietenia macrophylla* King, *Cedrela odorata* L., *Dipteryx odorata* [Aubl.] Willd.), successful management for multiple timber harvests will usually require intensive silviculture that increases establishment and growth rates. Methods such as seed bed preparation or seedling planting in logging gaps show promise when combined with periodic tending of established plants to reduce competition with faster-growing pioneer and vine species (Schulze 2003; Vidal 2004; Grogan et al. 2005).

The Vast Middle

Between these two ends of the continuum lie forests of many sizes and many subcategories of private and public landholdings. Should large private landholdings be held to the same strict standard as large public forests? Should

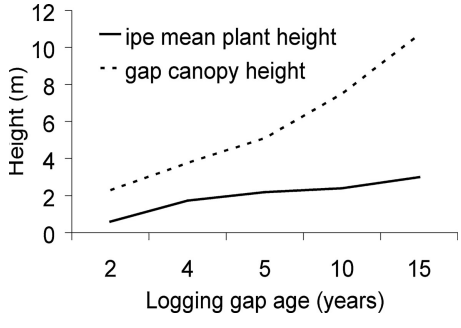

Figure 3. Mean juvenile height of T. impetiginosa *versus height of regenerating pioneer canopy in logging gaps.*

small communal forests be held to a higher standard than small private forests? We propose that forest-management regimes should aim for sustainability of total commercial volume production on all landholdings >3000 ha. This area corresponds to an estimate of what would be required for sustained production under the 25- to 35-year cutting cycle stipulated by recent regulation (Instrução Normativa 05/2006), and the regional standard of 100-ha cutting blocks. Moreover, above this size threshold most timber operations are of sufficient scale to support at least minimal investment in sustained production. Such a requirement would be a sensible additional condition of FSC-certification; FSC already recognizes the legitimacy of differential expectations based on ownership characteristics (FSC 2004*a, b*). According to the most recent available census information (IBGE 1996) rural properties in the Brazilian Amazon that are >2000 ha constitute 1% of the total number of properties but encompass an area of over 63-million ha (over half of the total area in private landholdings). Over 70% of this 63-million ha is occupied by landholdings >5000 ha—areas >3000 ha are not reported as a separate category.

The 25- to 35-year cutting cycle is likely too short in the absence of postharvest silviculture (Schulze et al. 2005), and the cutting block area may differ based on changes in technology and merchantable volumes. Hence, the 3000-ha cutoff should be adjusted upward or downward as cutting cycle durations and cutting block sizes are changed in response to improved information and technology. The certification process offers sufficient flexibility for such changes to occur. Periodic review of governmental regulations can provide for similar flexibility in Brazilian legal standards.

We recognize that a system of management requirements that vary by property size and ownership would require consistent and unambiguous classification of forest properties. Owners of multiple small properties, legally separate yet functionally united ownership groups, and industry–community partnerships blur distinctions between large and small forests and private and public. Fairly and effectively treating each of these gray areas in property classification is critical to the long-term success of a tiered forest-management system.

Costs and Benefits of Achieving Forest-Management Objectives

Achieving each of the management objectives listed in Table 1 becomes progressively more costly. Growth rates can be accelerated by vine cutting and liberation thinning, designed to reduce competition for future harvest trees (de Graaf et al. 1999; Finegan & Camacho 1999; Wadsworth & Zweede 2006). Some species may require more intense ground disturbance to foster successful regeneration; others may not persist unless they are planted and maintained (Fredericksen & Putz 2003; Pariona et al. 2003). Under what circumstance should these investments be made? Who should bear the costs? Should public policies compensate private forestland owners for the opportunity costs associated with achieving forest-management objectives that accrue public benefits? These are questions that apply to forests everywhere.

Applegate et al. (2004) recently assessed the distribution of costs and benefits associated with different RIL practices and argue that impediments to their adoption may be associated with a disconnect between who bears the costs and who receives the benefits. This debate sorely lacks a more comprehensive assessment of the distribution of costs and benefits associated with achieving forest-management objectives such as those we have outlined here. To illustrate this point, in Table 2 we list some of the major benefits and costs that are applicable to the management of Amazonian forest land for the objectives of (1) maintaining forest cover and species presence, (2) sustaining the total volume of timber harvested per unit area per cutting cycle, and (3) sustaining the volume of future harvests for each individual species. Substantial investment in management-oriented extension will also be necessary if any of these objectives are to be attained.

Standing forests, regardless of their long-term management potential, benefit society through ecosystem services (sensu Costanza et al. 1997) not furnished by agriculture or cattle ranching. Smallholders required to maintain forest cover and species presence only forego income that they might otherwise generate by illegal land-use activities. Management that would sustain timber yields (either at the stand or species level) entails significant additional costs of reducing initial harvest volumes and investing in postharvest silviculture. To the landowner the present value of increased future revenue that may result from those practices pales in comparison with the present value of their costs, which would be incurred decades prior to harvest. Nevertheless, such a restricted financial analysis excludes the social and environmental benefits that accrue to the public as forest management shifts toward more sustainable practices.

Rigorous assessment of the benefits and costs of forest management, and their distribution, could help guide the development of policy, regulation, and certification standards to ensure that the investment of public resources produces public benefits (e.g., income from harvests on public lands, tax revenue, ecosystem services) and that benefits that accrue to private forest landowners largely result from private investment. We suggest that the development of such standards should be guided by an explicit debate about what is both possible and desirable on forest landholdings that differ in size and ownership.

Table 2. Costs and benefits associated with objectives proposed for managing Amazonian forestland for timber production.

	Incremental costs		*Incremental benefits*	
Objective	*owner*	*public*	*owner*	*public*
Maintain forest cover and species presence	foregone opportunity of illegal conversion of forest reserve and illegal harvesting of rare species	enforcement foregone taxes on products of illegal activities	revenue from forestland uses elimination of risk of fines for illegal land use	ecosystem services (biodiversity, carbon accumulation, watershed protection, reduced albedo, stability of regional rainfall) timber harvest taxes
Sustain total volume production of currently commercial species	foregone opportunity of harvesting higher initial volume investment in silviculture	increased enforcement intensity foregone taxes on harvest of higher volume biodiversity loss associated with silvicultural practices	increased future harvest revenue increased long-term stability of volume production	increased future timber harvest taxes reduced risk of regional boom and bust economic cycles more, and more permanent, forest-sector jobs
Sustain volume production of each individual harvested species	foregone opportunity of harvesting higher initial volume of individual species investment in silviculture for those species	increased enforcement intensity foregone taxes on harvest of higher volume of individual species biodiversity loss associated with silvicultural practices favoring those species	increased future harvest revenue increased long-term stability of volume production for high-value species	increased future timber harvest taxes reduced risk of regional boom and bust economic cycles more, and more permanent, forest-sector jobs

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