Futures of Tropical Forests (*sensu lato*)

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ABSTRACT

When net deforestation declines in the tropics, attention will be drawn to the composition and structure of the retained, restored, invaded, and created forests. At that point the seemingly inexorable trends towards increased intensities of exploitation and management will be recognized as having taken their tolls of biodiversity and other forest values. Celebrations when a country passes the "forest transition" (i.e., suffers no net deforestation) will then be tempered by realization that what has been accepted as "forest" spans the gamut from short-rotation mono-clonal stands of genetically engineered trees to fully protected old growth natural forest. With management intensification, climate change, species introductions, landscape fragmentation, fire, and shifts in economics and governance, forests will vary along gradients of biodiversity, novelty of composition, stature, permanence, and the relative roles of natural and anthropogenic forces. Management intensity will increase with the increased availability of financial capital associated with economic globalization, scarcity of wood and other forest products, demand for biofuels, improved governance (e.g., security of property rights), improved accessibility, and technological innovations that lead to new markets for forest products. In a few places the trend towards land-use intensification will be counterbalanced by recognition of the many benefits of natural and semi-natural forests, especially where forest-fate determiners are compensated for revenues foregone from not intensifying management. Land-use practices informed by research will help minimize the tradeoffs between the financial profits from forest management and the benefits of retention of biodiversity and the full range of environmental services.

Key words: natural forest management; plantation forestry; REDD+; selective logging; silviculture.

TWEETABLE ABSTRACT: Environmentalists need to be aware that as a result of intensification of management, tropical forests spared from conversion may lose much of their natural value.

FUTURE FATES OF TROPICAL FORESTS will continue to be determined by market forces, labor availability, governmental policies, qualities of governance and institutional frameworks, and cultural values that interact in complex ways with the diverse impacts of climate change and the many effects of globalization. From environmental and long-term social welfare perspectives, these fates could be improved if interventions are designed to address the complexities of conservation in real-world landscapes (e.g., identifying and negotiating tradeoffs; Sayer *et al*. 2013).

While environmentalists will continue to prize natural capital stocks and biodiversity, the drivers of forest degradation, loss, gain, and modification will remain mostly financial, as mediated by governance (e.g., security of property rights; Agrawal et al. 2008), economic policies (e.g., taxes and trade barriers; Chomitz 2007, Rautner *et al*. 2013), and cultural proclivities (e.g., Meijaard *et al*. 2013). Strengths of these drivers vary with accessibility, as proposed by von Thünen (1826), adapted by modern economists and geographers (e.g., Chomitz 2007, Southworth *et al*. 2011, Angelsen & Rudel 2013), and modified to emphasize the high cost of property right security near forest frontiers (Hyde 2012). Basically, improved access increases potential land rents while it spurs immigration and promotes good governance. These trends are reinforced by the fact that many areas that remain remote are otherwise unsuitable for intensive land uses due to steep slopes, high elevations, and/or particularly infertile soils.

Rather than repeat the ample contents of several recent analyses of the rates and drivers of tropical forest loss and recovery (e.g., Pfaff *et al.* 2010, Wright 2010, Corlett 2011, Rautner *et al*. 2013, Köthke *et al.* 2013, Krupnick 2013, Wilcove *et al.* 2013, Laurance *et al.* 2014), we focus on the natures of forests that will remain standing and those that will be restored or created. Our main point is that the undesirable environmental impacts of forest use can be minimized if there is a desire to do so and if attention is paid to the structure, composition, and dynamics of the antecedent and consequent ecosystems and landscapes and not just on the total land surface occupied by forest. This focus is further justified by recent evidence of accelerated fluxes in forest cover, with losses exceeding gains but without a clear sense of the equivalence of what was lost and gained (Hansen *et al.* 2013). Our concern is that without clarity on this issue, areas spared from agricultural conversion will not be spared from use and will little resemble natural forests.

To reveal the consequences of land-use change to forests, clarity is needed about what is meant by “forest,” “forest degradation,” “reforestation,” and “restoration.” Unfortunately, previous efforts at elucidation mostly failed perhaps because of the inherent complexities of classifying conditions that vary continuously and often subtly (e.g., Lund 2002, Sasaki & Putz 2009, Putz & Redford 2010; but see Thompson *et al.* 2013). That many forest states are not easily differentiated with remote sensing is another impediment and perhaps motivates continued reliance on the definition of "forest" by the Food and Agricultural Organization of the United Nations as an area of >0.5 ha with >10% potential tree cover, with "trees" defined as plants (including palms and bamboo) capable of growing to >5 m tall (FAO 2010). With "arborealization" of international conservation agendas, such a broad definition may help legitimize claims of forest dependency and confer political and even financial benefits (Walker 2005). Finally, a broad definition favors some geo-political agendas and businesses such as the restoration firms and forest industries that benefit if large areas are deemed deforested or degraded.

To illuminate the environmental consequences of different land-use practices, the states of ecosystems and landscapes need to be assessed relative to an agreed upon reference condition. With on-going changes in cultures, climates, and other ecosystem-shaping factors (e.g., increased nitrogen deposition), reference states need to be flexible enough to accommodate change, but they still need to be specified. In full recognition of the cultural trappings and biophysical impossibilities of truly and fully natural, wild, pristine, primary, primeval, or virgin forests (e.g., Soulé & Nease 1995), we here cling to this ideal in our reference state selection of "old growth forest." What constitutes old growth is not free of cultural values and varies among forest types, so here we rely on the most general definition *as an area with naturally regenerated trees older than the silvicultural or economic rotation age* (modified from Spies & Duncan 2009). We contrast old growth with forests that are managed, degraded, secondary, planted, restored, novel, or domesticated. To the extent that biodiversity confers resilience against environmental shocks and stresses, old growth should be more resistant to change and resilient to perturbations than these derived states (e.g., Messier *et al.* 2013). Our emphasis on old growth is in no way meant to diminish the values of degraded primary, secondary, and other sorts of forests or of trees outside forests. We also recognize that other reference states would be more relevant in other contexts such as where there is no old growth.

Natural forest values are jeopardized when land-use decisions are informed by remote sensing analyses that distinguish only forest and non-forest and when "forest" is defined solely on the basis of tree cover. These practices engender somewhat false senses of accomplishment when the forests reported to cover substantial portion of tropical landscapes little resemble old growth.

FAO's efforts to separate "planted forests" are commendable (FAO 2010), but it is not clear why short-rotation monoculture fiber farms are accepted as "planted forests" but simple as well as complex multispecies agroforests are not [e.g., African oil palm (*Eleais guineensis*) and rubber (*Hevea brasiliensis*) plantations, shade-grown coffee (*Coffea* spp.), and dammar gardens and other domestic forest types; Michon *et al.* 2007]. Certainly many sorts of agroforests maintain more biodiversity and provide more forest services (e.g., canopy cover and carbon storage) than short-rotation fiber farms of woody species (e.g., Barlow *et al.* 2007, Vandermeer and Perfecto 2007).

As a further illustration of the importance of clarity about what is meant by "forest" as well as "reforestation" and "restoration," consider the consequences of a country passing the "forest transition" (i.e., the point in time when forest losses and gains balance; for recent reviews see Perz 2007, Gregersen *et al.* 2011, Angelsen & Rudel 2013). If the forest gains came from planting native or non-invasive exotic trees in deforested and severely degraded areas such as over-grazed and eroded pastures on steep slopes, then the transition should be celebrated. If the restored areas contribute to the well-being of local people, then so much the better. In contrast, consider industrial monocultures of invasive exotic and low water-use efficiency trees that replace secondary forests or naturally non-forested ecosystems such as savannas or grasslands; these too might confer some social and economic benefits, but with high biodiversity costs (Putz & Redford 2009; Stickler *et al*. 2009). Similarly, passing the forest transition has negative consequences for human welfare if that accomplishment involved reduced food production or loss of local control as when agribusinesses accumulate lands from smallholders to plant non-food commodities (Zoomers 2010).

If old growth forest is the reference state against which other ecosystem states are compared, then it should be recognized that many old growth characteristics (e.g., large trees) are slow to accrue. Although the environmental values of secondary forests (i.e., forests that develop in previously cleared areas) are substantial and increase over time (e.g., Chazdon *et al.* 2009; Hall *et al.* 2011, but see Van Breugel *et al*. 2013), full recovery of old growth values occurs at centennial scales and then only under appropriate conditions (e.g., availability of propagules of native species and the dispersal agents to transport them, isolation from the onslaught of exotic species, and continued climatic suitability).

We refer to losses of old growth values from areas that remain forested as "degradation." Thompson *et al.* (2013) present an operational framework for consideration of many sorts of forest degradation. They propose ways to conceptualize and measure losses of a forest's productive and

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protective functions, biodiversity, and carbon, as well as whether the area is subjected to unusual disturbances (e.g., alien invasive species or altered fire regimes). Clarity about how and to what extent a forest is degraded will also inform decisions about the extent to which natural recovery mechanisms can be relied upon and where investments in restoration are warranted. To be avoided are situations in which forests designated as degraded are automatically rendered available for intrusive restoration or conversion (Sasaki & Putz 2009, Barr & Sayer 2012).

One problem with the use of old growth as the reference state is that most forest management interventions will thereby constitute degradation. Thompson *et al.* (2013) suggest that to avoid this conundrum, sustainably managed forests (SFM) should replace for primary forest as the reference condition. We agree with this suggestion but caution that timber yields can be sustained at landscape levels by either very gentle or very harsh silvicultural treatments (e.g., light harvests over large areas at long intervals or heavy harvests followed by enrichment planting in concentrated areas, respectively). Once again, clarity is needed about what is being lost and gained relative to a defined and accepted reference state.

A GRADIENT OF FOREST USE INTENSITIES

Although forests (*sensu lato*) vary along non-orthogonal gradients of structure and composition while they differ in the reasons for their continued existence or re-creation, their condition can often be predicted from their accessibility (Fig. 1). For example, in accessible areas where land tenure is relatively secure and both human population densities and potential land rents are high, most of the forests present are likely to be planted or at least intensively managed. Depending on tenure type, property size, capital availability, institutions, and markets, the plantations might be of African oil palm, rubber, or any of a variety of other tree species grown for fruit, seed, fiber, timber, biomass, or biofuel. The biodiversity and other natural values of these plantations vary with management intensity and practices (see the *Tradeoffs* section below). In a few accessible areas where "protective rents" are more valued by society than the possible "productive rents" (Angelsen 2010), tree plantations are established to restore ecosystem services (e.g., erosion control) while some fragments of semi-natural forest remain standing (e.g., sacred groves; Bhagwat & Rutte 2006) or be allowed to recover. At this end of the Von Thünen gradient most forests are surrounded and affected by more intensive land uses and prone to degradation by exotic species invasion, edge effects, and altered fire regimes.

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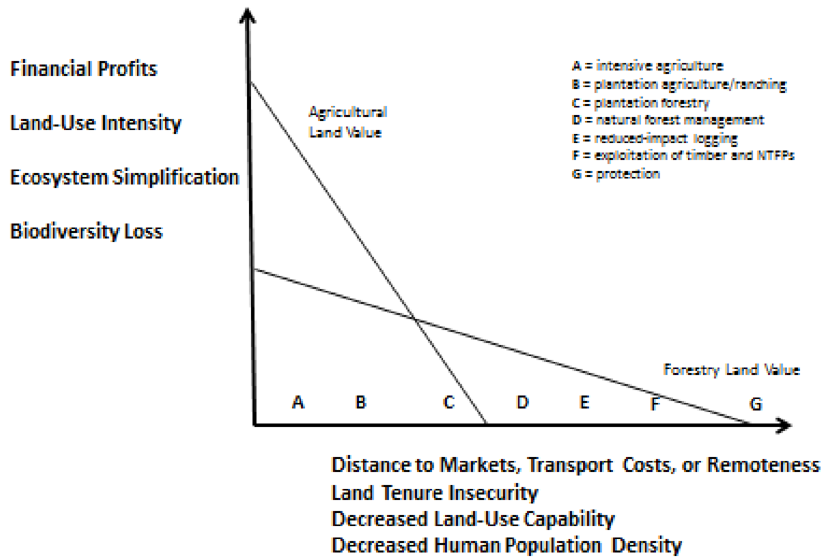

FIGURE 1. A modified Von Thünen diagram that depicts generalized relationships between the profits and consequences of different intensities of agricultural and forestry land uses (A-G) versus accessibility and its correlates (e.g., human population density, land-use capability, and the costs of securing property rights). Likely land uses along the accessibility gradient are noted; natural forest management is for multiple uses and involves reduced-impact logging (RIL) plus various silvicultural treatments.

In rural areas of moderate accessibility and substantial human presence, forests develop that are novel in composition, structure, and dynamics. These novel communities often emerge near human settlements where propagules of invasive exotic species are abundant (e.g., Lugo 2009). Novel communities also develop where fire suppression allows trees to invade savannas and open woodlands (e.g., Hoffman *et al*. 2012). Despite their often radical difference from old growth forest, many of these novel ecosystems are be valued for the goods and services they supply (Hobbs *et al*. 2013).

On lands of intermediate accessibility and use value, some previously cleared forests are reforested with native or exotic tree species for commercial purposes or to cash in on environmental incentive programs. Other areas revert naturally to forest through secondary succession due to shortages of agricultural labor or where conditions are unsuitable even for plantation forestry (Harvey *et al.* 2008; Nagendra & Southworth 2009). At this access level, where land tenure is sufficiently secure and the necessary financial capital and, knowledge are available, some land-owners manage their secondary and badly degraded forests to increase wood production or other purposes. Where these conditions do not exit, the patches of forest are exploited for timber, fuelwood, and other forest products whenever it becomes financially remunerative to do so. The fauna in these forests varies with hunting pressure, biophysical conditions (e.g., connections with source areas), and other factors (e.g., introductions of exotics).

In less accessible areas where human population densities and the financial opportunity costs of forest retention are both low, exploited and managed semi-natural forests cover an increasingly large proportion of the landscape. Whether exploitation or management prevail remains mostly a function of tenure regimes with their associated rights and responsibilities coupled with institutional capacities to exercise these rights and obligations. For example, forest fates are likely to differ between lands granted to well-capitalized timber concessionaires and those controlled by indigenous communities (e.g., Nolte *et al.* 2013). That said, company-community partnerships can result in land-uses that range from low-intensity selective logging to forest conversion for industrial agriculture. And if financial opportunities arise, even officially demarcated protected areas are not immune to being degazetted and converted (Mascia and Pailler 2011).

With further decreases in accessibility, the costs of securing property rights increase substantially and governance failures allow repeated uncontrolled harvests of timber and other forest products. Finally, further into the frontier, forests are demarcated as protected areas or exploited for their high-value-to-mass non-timber forest products (e.g., hides, gums, incense woods, and medicinal plants) because alternatives are financially unattractive.

Over time, forest fates in most countries or at least large regions within countries have followed the trajectories described above (e.g., Hyde 2012, Angelsen & Rudel 2013). According to this *developmentalist* model (e.g., Lane & McDonald 2002), the sequence starts with a prehistoric era of low intensity subsistence use by scattered indigenous people. Much later when human populations increase and society recognizes the value of forests and especially the value of a sustainable supply of wood, governmental forest reserves are typically established and management evolves from a focus solely on timber to management for a wide range of goods and ecosystem services. Mather (2001) posited a further phase of post-industrialism for when biodiversity conservation, recreational use, and existence values determine the fates of some forests. The distinctiveness and durations of these stages have varied within and among countries and over time, but the basic transition from exploitation and liquidation to management and protection seems to apply across the globe (e.g., Hyde 2012).

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FUTURE TRADEOFF TRAJECTORIES ALONG THE FOREST-USE INTENSITY GRADIENT

To explore some of the possible ways to rectify the consequences of sub-optimal forest uses, we describe a variety of policy and practice pathways towards more natural forest conditions that are at least revenue neutral. The focus is on nature-profit tradeoffs along the accessibility gradient described above.

Perhaps the most effective conservation tactic for all sorts of forests regardless of their location is avoidance of uses that cause more biodiversity loss than necessary to secure the desired productivity or profitability. When depicted in terms of the maximum attainable biodiversity conservation over a range of forest-use intensities, the conditions to be avoided are those that fall inside this production-possibility frontier (Fig. 2). In this section we present a series of examples of unnecessarily intensive or otherwise environmentally sub-optimal forest-use practices that are common along the Von Thünen gradient described above. In the parlance of the land-sharing versus land-sparing debate (e.g., Ewers *et al.* 2009, Phalan *et al.* 2011, Tilman *et al*. 2011, Laurance *et al*. 2014), we focus on land spared from agricultural expansion. Admittedly this focus is obscured when the intensive agriculture is not for staple foods (e.g., luxury vegetables and fruits) or for biofuel and other products. For example, palm oil is currently used predominantly for food, but also has markets as a biofuel as well as for cosmetics and lubricants. It also seems relevant to note that the stems of this species are increasingly used for flooring, veneer, and other standard forest products (Nordin *et al.* 2004, Wan Asma *et al.* 2012). Similarly, the recent market penetration of rubberwood highlights one of the complications in the land-sharing and sparing debate. Finally, it should also be noted that lands spared from both agricultural and forestry uses might nevertheless be used for mining (e.g., Edwards *et al*. 2013).

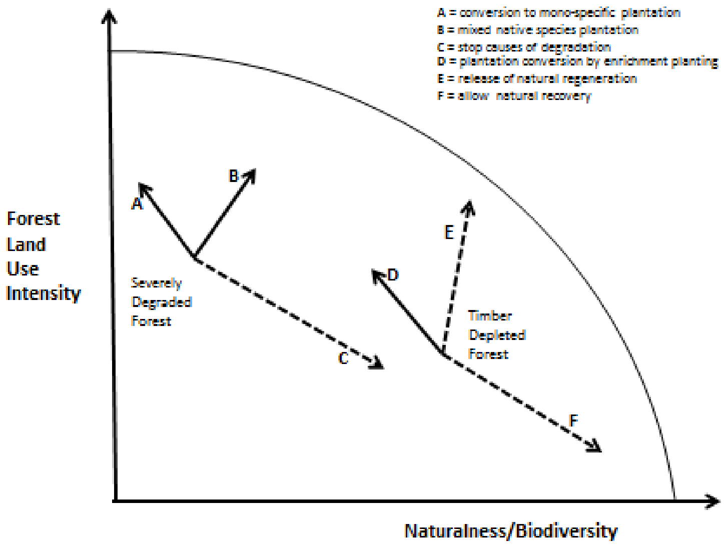

FIGURE 2. A diagrammatic representation of the tradeoffs between forest-use intensity and the maintenance of the biodiversity or “naturalness” of old growth forests relative to the production possibility frontier (PPF), which represents the best possible compromise. Plausible management practices for two forest states beneath the PPF are depicted. Note that the PPF depicted is a theoretical construct, but resembles those that typically emerge when tradeoffs are complex.

In accessible areas with arable soils and substantial population pressure, forest management tradeoffs will relate mostly to planted trees grown as agricultural crops. Examples include trees on farms, agroforestry and agrosilvopastoral systems, and industrial plantations managed for a multitude of uses including shade, wind-brakes, fruit, charcoal, biomass feedstock, pulp and saw timber for high-end uses (e.g., furniture). Intensively managed plantations can attain rates of biomass and timber volume accumulation an order-of-magnitude higher than natural forests with further increases likely with genetic and technological improvements (e.g., Carle & Holmgren 2008). Some planted stands can also contribute to the well-being of poor people (e.g., by providing fuel-wood and employment), others help control erosion, and an increasing proportion supply global markets with forest products. The expansion of plantation forestry will likely continue, if not accelerate, in response to emerging markets, improved access and governance, new technologies, environmentally perverse policies, and increased awareness of the associated business opportunities (e.g., Asen *et al*. 2013). In the absence of proper land-use plans, plantations owned by companies and communities will likely replace some natural forests and displace food production (e.g., Boulay and Tacconi 2012).

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For relatively accessible forests severely degraded by wildfires and over-harvesting we consider three land-use trajectories that differ in management intensity and biodiversity impacts (Fig. 2). Trajectory A represents conversion to an industrial monoculture, B is a mixed plantation with natural forest buffers along streams, and C represents the unlikely scenario of cessation of degradation followed by secondary succession or active restoration. Despite some evidence to the contrary (e.g., Kanowski & Catterall 2010, Paquette & Messier 2013), the preponderance of Trajectory A suggests that there are financial costs associated with managing plantations to more resemble natural forests. Additional research carried out at appropriate spatial and temporal scales is needed to show how the productivity as well as the profitability of intensively managed plantations can be maintained or enhanced with increased within-stand diversity in the over- and under-stories as well as by maintenance of natural forests in riparian and other environmentally sensitive areas (e.g., Brockerhoff *et al*. 2012, Paquette & Messier 2013). Translations of this new knowledge into packages of practices that deliver financial, biodiversity, and other benefits will need to consider the constraints and possibilities for the full range of forest owners and operators (e.g., governments, communities, private landowners, and industrial firms). Widespread adoption of these diversifying practices will happen only after the associated operational and marketing challenges are adequately addressed or compensation mechanisms are developed (e.g., payments for biodiversity). Until researchers demonstrate to the satisfaction of plantation managers the benefits of more close-to-nature silviculture, monoculture stands are likely to continue to dominate the plantation sector and many landscapes considered to be forested.

In defense of Trajectory A (Fig. 2), there apparently are socioeconomic, cultural, and political conditions under which intensively managed forestry plantations reduce pressure on natural forests as sources of timber and other forest products (e.g., Sedjo & Botkin 1997). New Zealand is often used as an example of where natural forests on public land were spared from logging after much the country's landscape was converted into plantations of exotic trees (Maclaren 2001). That example notwithstanding, it is not clear when and where this natural forest sparing tradeoff is likely. In the only study on this topic of which we are aware for tropical forests, Ainembabazi and Angelsen (2014) found that proximity to plantations established in degraded forests in Uganda only slightly improved the fates of nearby natural forests. The benefits are even harder to see in the Southeastern USA where despite the private ownership of much of the forest, high labor costs, huge expanses of extremely productive plantations, substantial development pressure, and considerable wealth,

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logging continues apace in an increasingly small area of semi-natural forest (Hyde 2012). Nevertheless, avoidable losses of natural forests can be reduced if they are valued by society, strong local institutions and accountability systems support forest-friendly land management decisions, cultural values are recognized and incorporated in the design and implementation of incentive mechanisms, and the full range of forest users are considered when forest access and use policies are formulated and implemented (e.g., L'Roe & Naughton-Treves 2014).

Insights from the literature on agricultural intensification as a means to reduce forest conversion might reveal the conditions under which intensification of forest use in selected areas will allow forests in other areas to regain or retain their natural values (i.e., be spared). Both empirical (Phalan *et al.* 2011) and theoretical (Tilman *et al*. 2011) studies demonstrate the landscape-scale carbon and biodiversity benefits of intensification of food production. How biofuel production will affect the land-sparing versus land-sharing tradeoff is less clear but the results of full carbon accounting exercises represent only one element to be considered. What is clear is that areas spared from agricultural conversion and mining are unlikely to be spared from other sorts of management. Fates of spared forests will vary with a range of factors that include accessibility, labor availability, societal values, substitutability of plantation products for those from natural forests, land tenure, and a suite of institutional and policy factors (e.g., incentives for competing land uses, costs of compliance with burdensome regulations, and law enforcement; Kaimowitz & Angelsen 1998, Angelsen 2010, Pirard & Belna 2012).

In areas beyond the agricultural frontier that are depleted of their commercial timber stocks by overharvesting, well-intentioned efforts at restoration can result in unwarranted biodiversity losses (Sasaki & Putz 2009, Kettle 2012). One commonly advocated path towards restoration involves planting of native species of commercial value in cleared areas, which should be referred to as plantation conversion by enrichment planting (Trajectory D, Fig.2; Evans 1982). In Indonesia, for example, after selective logging the government now requires that tree seedlings be planted at 2.5 m spacing along 3 m wide clearcut strips opened at 20 m intervals (KKRI 2010). While the planted trees remain standing, the biodiversity effects of this intervention are surprisingly minor (Berry *et al.* 2010; Ansell *et al*. 2011). Unfortunately, when these planted trees are harvested after 25-30 years, the logging intensity will be so high that the effects will be devastating regardless of the harvesting techniques employed (e.g., Sist *et al.* 1998).

Enrichment planting can be warranted where logged forests lack natural regeneration of commercial species, but this intensive treatment is too often motivated by the mistaken idea that forest management necessarily involves tree planting. More gradual but similarly intensive forest domestication is sometimes carried out by forest-dwelling rural people who often manage for a wide diversity of forest products (e.g., Michon *et al.* 2007). An alternative and gentler path towards natural forest restoration of areas that have lost their commercial growing stock involves the release from competition of naturally regenerated seedlings, saplings, and pole-sized trees of the desired species (Fig. 2, Trajectory E). Application of this approach requires forest workers and forest inspectors who can recognize all the commercial species, but can still be both cost-effective and biodiversity friendly. Perhaps the best option is a hybrid approach that rewards workers equally for planting or discovering and releasing commercial species. Under appropriate social and political conditions where funds are available, some of these degraded forests might be purchased and protected from further logging (Fig. 2, Trajectory F; Rice *et al.* 1997, but see Romero & Andrade 2004 and Karsenty 2007).

A final example of a tradeoff between management intensity and biodiversity impacts (not depicted on Fig. 2) involves avoidance of one of the principal causes of degradation close to forest frontiers, uncontrolled timber exploitation by untrained crews. There is no need to review here the already ample evidence for the environmental benefits of training forest workers and adoption of reduced-impact logging (RIL) practices; these benefits include enhancements in biodiversity, carbon storage, and hydrological functions and come at modest costs or financial savings (e.g., Medjibe & Putz 2012 and references therein). These benefits can be further enhanced if RIL is combined with gentle silvicultural practices such as liberation of liana-laden future crop trees (Peña-Claros *et al.* 2008).

In a recent study of sparing and sharing of selectively logged forest in Borneo, Edwards *et al.* (2014) provide more evidence for the benefits of the former based on data on abundances and species richness of birds, dung beetles, and ants. Their simulations indicate that in contrast to the impacts of low intensity logging over entire concessions, biodiversity benefits if loggers harvest timber intensively in some areas in exchange for protection of portions of primary forest; profits are equalized when 25% of the area is not logged. Actually, if stipulations about logging in riparian buffer zones and on steep slopes are respected, often more than that portion of concessions remains unlogged for legal as well as logistical reasons (FEP, personal observation). Whether that spared forest is equivalent in biodiversity value to the areas that are logged remains to be determined; if the values of hydrological functions (e.g., erosion control) and aquatic biodiversity are included in the equation, then those spared areas might be of even higher value. Also to be considered on Borneo is the Indonesian government's requirement that after intensive harvests, concessionaires need to clearcut strips and plant timber tree seedlings through logged-over forest (see below). Finally, it is unfortunately the case that much of Borneo has already been logged at least once (Griscom *et al.* 2014), which means that comparisons with large tracks of old growth are no longer of much relevance in many areas.

HOPES FOR NATURAL FOREST

Fiscal incentives for natural forest retention based on market capture of environmental benefits will continue to be required because natural forest management for timber competes poorly with more intensive land uses under all but the most adverse conditions (e.g., Pearce *et al.* 2002; Fisher *et al*. 2011; Ruslandi *et al*. 2011). Natural forests might also benefit from the realization of market advantages for certified products from responsibly managed natural forests and effective restrictions on illegal logging but suffer if new uses and markets for wood from tropical trees (e.g., nanocrystalline cellulose and cellulosic ethanol) motivate management intensification.

CONTRIBUTIONS OF CAPACITY BUILDING.--Tropical foresters will continue to manage the rapidly expanding timber, biofuel, and fiber plantations but some will focus on more close-to-nature approaches to natural forest management. In the already substantial and growing areas of secondary forests that are not agricultural fallows destined for re-clearing, foresters will manage some stands to enhance their biodiversity, timber, carbon, or other values. In degraded natural forests, forestry expertise coupled with appropriate policies and incentives will be marshaled to mitigate the damage caused by premature re-entry logging, wildfires, and other abuses. It is also likely that with increased societal scrutiny of forestry practices made possible by new remote sensing methods, portions of designated production forests that are unsuitable for management (e.g., due to high risks of landslides) or that of especial conservation value will be taken out of production and protected. With proper landscape-level plans that designate some forests for full protection, others for close-to-nature management for multiple objectives including forest products, and some managed intensively, the tradeoffs between production and protection can be minimized (e.g., Côte *et al.* 2010).

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The transition from timber exploitation to forest management can happen only if there are adequate numbers of appropriately trained foresters and forest laborers. Forestry training programs need to embrace the increased diversity of demands on their graduates. Unfortunately, many of these programs have closed and most have morphed to the extent that their graduates are no longer equipped to design and implement sound timber harvests or to prescribe and apply appropriate silvicultural treatments where timber yield maximization is not the sole goal (Guariguata & Evans 2010). Many tropical foresters are uncomfortable dealing with diversities of stakeholders, few can correctly identify more than a handful of commercial timber species (Baraloto *et al.* 2007), and most know much more about plantations than natural forests. In managed natural forests, professionalization of the work force will help improve management practices, but this will require steady funding for training of tree finders and fellers, skidder drivers, and logging crew bosses as well as incentives to implement good practices (Putz & Romero 2012). One reason why tropical forestry is not attracting many of the best and brightest students is that, despite the modest impacts of selective logging on biodiversity (reviewed by Gibson *et al*. 2011, Putz *et al.* 2012), foresters and forestry are sometimes vilified and often ignored (e.g., Semple 2013). Furthermore, managed natural forests are typically remote, the work is physically demanding, and field forester salaries are generally low. Improvements in remote sensing will help, but a culture of hearty field foresters needs to be rejuvenated.

ACCEPTANCE OF NATURAL FOREST MANAGEMENT AS A CONSERVATION OPTION.--With increased urbanization and attendant reductions in public exposure to forestry, the tendency to disregard the conservation potential of natural forest management is likely to increase (White 1995). The more the benefits of responsible the land-use are made evident, the higher the likelihood that it will expand. It will help if research is framed in conceptual spaces with social, economic, and cultural dimensions and carried out in participatory manners with representatives of logging firms (including those run by communities) and governments. When more attention is paid to natural forest management as a conservation strategy, ways will surely be discovered to mitigate the deleterious environmental and social impacts of logging and other silvicultural treatments. These contributions will be enhanced if conservation-minded researchers spend more time in managed forests and come to understand more fully the cultural, economic, engineering, and ecological dimensions of silviculture. If changes in attitudes and perceptions about forest management come to pass, future reviews of landscape-level management practices will also feature the richness of multiple-objective natural forest management rather than just living fence posts, agroforests, and secondary forests (Gardner *et al.* 2009). While pluralistic approaches to conservation will most likely prevail, we can expect the occasional pundit to dismiss tropical forestry as unsustainable and to exhume arguments against any sort of conservation other than complete protection.

With abundant high-quality research emerging from managed forests, fewer informed researchers will confound exploitative log mining (i.e., degradation) with responsible forest management. This step towards differentiation of exploitation and management will be facilitated if the avoidable and unavoidable tradeoffs associated with forest-use are revealed, discussed, negotiated, and minimized. For this to happen, decision-makers first need to accept that silvicultural practices are prescribed to favor particular species, functional groups, or life forms at the expense of others (e.g., enhancing the survival and growth of future crop trees by girdling non-commercial neighbors).

ECONOMIC CONSIDERATIONS.--As demands for tropical timber increase and illegal supplies dwindle, prices should increase especially given that supplies already peaked in much of the world (Shearman *et al*. 2012). That prices have not already climbed substantially is distressing, but this peculiar condition results in part from abundant illegal supplies and blockage of scarcity signals by over-sized processing industries and compliant forest management agencies. Demands for timber are also satisfied by legal but pre-mature re-entry logging and logs from areas where timber should not be extracted due to high environmental value or sensitivity. Continued improvement in the enforcement of forest and trade laws partially due to international efforts like the European Union's FLEGT Program (Dooley & Ozinga 2011) should complement rigorous third-party certification to expand the area of tropical forest under responsible management (Romero *et al.* 2013). Although it will be socially disruptive, were timber stocks are depleted, some forest industries and their associated governmental agencies will need to be down-sized, but might then be re-tooled to accommodate a wider range of responsibilities including restoration and recreation.

On sites marginal for agriculture, regardless of their accessibility, for-profit natural forest management for timber and non-timber products can tip the financial balance towards forest retention. In contrast, on arable lands in accessible areas, the financial opportunity costs of forest retention will often be too high for investors, property owners, and government officials (e.g., Butler *et al*. 2009). This financial reality means that other than where cultural factors intervene, natural forests will continue to be sacrificed for production of food, fuel, and fiber as well as for suburban and exurban sprawl (e.g., Fisher *et al.* 2011).

INSTITUTIONAL CONSIDERATIONS.--How forests are affected by economic development and improved governance will continue to depend on whether the concern is about deforestation or degradation, with the identities of the responsible parties, and with the pertinent drivers. At least over the short-term and where population densities are low, poverty, political instability and social conflict, non-democratic regimes, lack of devolution, smuggling of drugs and other contraband, and poor infrastructure can all protect forests from large-scale conversion because they increase financial risks and cause capital constraints (e.g., Price 2003, Larjavaara 2012). Under high population pressure, in contrast, these same factors often promote large-scale forest degradation and deforestation from a multitude of small-scale events. What is clear is that land-use decisions need to be informed by knowledge about the tradeoffs between the financial benefits of forest management intensification and the associated costs in biodiversity and other natural forest values.

Devolution of control over forest lands to rural communities in the tropics is poised to accelerate (e.g., Agrawal *et al*. 2008, Pokorny and Johnson 2008; Bowler *et al.* 2011), but it is not clear whether this power shift will change the fates of many forests. Rates of large scale conversion may decline, at least as long as these communities remain poor, poorly organized, and beset with land tenure problems and governance failures (e.g., Börner *et al*. 2010). Under these conditions, payments for environmental services, including carbon retention, as well as certification of products from well managed forests, could tip the balance towards forest conservation if their implementation effectively thwarts governance failures. When forest-controlling rural communities accrue financial and institutional capital, such payments and supportive novel institutional and legal regimes could steer them away from land-use intensification that lead to forest cover loss or replacement by plantations (Feintrenie *et al.* 2010, Guillerme *et al*. 2011). These instruments should recognize that the values members of these communities place on nature vary and are subject to change in response to economic opportunities and environmental education (Coomes *et al.* 2008, Pfund *et al.* 2011, Meijaard *et al*. 2013).

Whether the determiners of forest fates are rural people, government functionaries, or board members of multi-national corporations, management intensities will likely continue to vary with market demands, availability of financial capital and labor, security of property rights, site capabilities, accessibility and the associated costs of management, and cultural preferences (e.g., Rudel *et al*. 2002Alternatives to environmentally destructive management intensification on lands spared from agricultural conversion will only become likely if there is recognition of the variety of states that can be considered forest. It will also help if the local, regional, and global benefits of natural forest (e.g., Oliveira *et al.* 2013) are taken into account when decisions are made about land-use intensification.

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