ISTF NEWS

5400 Grosvenor Lane

Bethesda, Maryland 20814, USA

Special Report, January 2010

CARBON BENEFITS FROM AVOIDING AND REPAIRING FOREST DEGRADATION*/

Chapter 45 in National REDD Architecture and Policies (forthcoming)

Francis E. Putz (fep@ufl.edu) and Robert Nasi

Synopsis

- Stopping illegal timber harvesting and adopting reduced-impact logging in the tropics, together with wildfire suppression, could cost-effectively reduce carbon emissions and enhance carbon uptake.
- Carbon uptake in degraded forests could be enhanced by better post-logging forest management practices and active restoration.
- REDD+ goals related to forest degradation are achievable due in part to recent improvements in remote sensing techniques for monitoring logging and wildfires coupled with increasing availability of hand-held global positioning systems, especially if the synergy with on-going forest certification is fully utilized.

Introduction

International discussions about REDD have focused on deforestation, with little regard for the more damaging, but equally extensive, processes of forest degradation. While less well studied, emissions from unsustainable wood extraction (poor logging practices and overharvesting of timber and fuel wood) and wildfires are estimated to contribute comparable amounts of emissions as deforestation (Asner *et al.* 2005; FAO 2006; Gibbs *et al.* 2007; Putz *et al*. 2008a). Furthermore, forest degradation is often enhances the likelihood of subsequent deforestation. Finally, and not least, in the interest of adaptation to climate change, losses of resilience in degraded forests are of great concern (Guariguata *et al*. 2008).

This chapter focuses on the carbon benefits arising from better forest management (i.e., training workers, planning harvests, and using reduced-impact logging techniques plus postharvest silvicultural treatments (RIL+), and coordinating fire detection and suppression (fuel wood harvesting is discussed in Chapter X). We also discuss options for restoring degraded forests to enhance rates of carbon uptake and storage. By treating forest degradation solely in carbon terms, we do not mean to discount the dangers of a focus on carbon for biodiversity and social welfare (Putz and Redford 2009).

Why is there still so much tropical forest degradation?

High opportunity costs of maintaining (some) forests

The reason why forests continue to be misused, despite huge efforts at reform, is that often misuse, such as harvesting timber without regard for sustainability, is more financially rewarding than careful management (Rice *et al.* 1997; Pearce *et al.* 2002). In terms of the Von Thűnen framework (Karsenty *et al.* 2008), the opportunity costs of maintaining forests increase as the industrial forestry rent frontier is approached. In other words, where improved access means forested land becomes suitable for plantations, agricultural crops, or pasture, standing trees become obstacles to intensification of land-use (although harvesting and selling timber can defray the costs of clearing). In patchworks of remnant forest and agricultural land, wildfires interfere with forest management and damage commercial plantations of fire-sensitive species such as citrus (Nepstad *et al.* 2001). Beyond the agricultural frontier where access is poor, terrain is difficult, soils are unsuitable for intensive cropping, and weak governance often precludes investment in long-term management of any sort, rapid, repeated logging is the most likely and the most financially prudent land use (Chomitz 2006). Under such conditions, loggers might financially benefit from adopting some cost-cutting and less destructive harvesting techniques (e.g., planned skid trails to reduce fuel consumption), but they would not gain from adopting the whole package of improved forest management techniques (Putz *et al.* 2008a). Therefore, many of the recommended management practices are only likely to be adopted where effective enforcement of regulations is backed by financial incentives. These prerequisites mean that REDD+ interventions will often have clear additionality.

Insecure tenure The lack of long-term, legally binding, forest management concession agreements and other forms of resource tenure is one of the greatest impediments to better forest management (de Graaf 2000). For both communities and concessionaires, insecure tenure precludes solid contracts and raises discount rates in the private sector (Richards and Moura Costa 1999). More generally, weak forest governance and insecure tenure serve to increase the opportunity costs of maintaining forest, foster widespread illegal logging, and keep timber prices low (Tacconi 2007). On the other hand, secure tenure can provide access to capital and consequently foster forest destruction if intensification of land use is financially and culturally attractive and not precluded by enforced governmental regulations (Gould *et al.* 2006)

Inappropriate policy and regulatory frameworks

Loggers and landowners justifiably complain that forest regulations are unduly complicated and seemingly created by authorities who do not understand the socio-ecological context in which they are to be implemented. A related deficiency is that scarcity of extension services in most tropical countries exacerbates the problems associated with drawing up and following forest management plans or protecting forests from wildfires.

Where government regulations are forest oriented, ineffective enforcement constrains the adoption of good forest management practices. All too often, forest managers are accustomed to operating in environments in which they can easily manipulate or simply disregard performance requirements. There is clearly a need to change this condition and to foster effective enforcement lest REDD+ initiatives suffer the same fate as many other well intentioned efforts to promote better forest management (Levin *et al*. 2008).

In many tropical countries, governance failures reinforce norms that are contrary to good forest management. In addition to ineffective law enforcement and corruption, a perceived lack of government interest in long-term management, perceived discrimination against the timber sector and inconsistent, and sometimes conflicting, regulations all contribute to mismanagement. As a result of decades of weak governance, loggers opt for short-term gains from extraction and feel entitled to violate laws. The Peruvian (Smith *et al.* 2006) and Cameroonian (Cerutti *et al.* 2008) experiences show that it is easier to change laws than to implement them effectively.

Lack of trained staff, limited technical guidance and inappropriate wage systems

Worldwide, about 350 million hectares of tropical forests are designated as production forest, about a third of which is controlled by rural communities and indigenous groups (Sunderlin *et al.* 2008). These forests are exploited mainly for timber and,given growing demand and better access, logging is likely to expand. Because of the diversity of natural forests and limited markets for the timber of most species, loggers usually only harvest between 1 to 20 trees per hectare. Unfortunately, for every tree harvested by untrained and unsupervised fellers and machine operators working without detailed maps, some 10 to 20 others are severely damaged (Putz *et al.* 2008a; Sasaki and Putz 2009). Numerous studies have shown that with appropriate harvesting plans and training (reduced-impact logging; RIL), 50% or more of this collateral damage can be avoided. It is also known that silvicultural treatments applied after logging, such as clearing competitive species from around future crop trees, can double rates of recovery (Wadsworth and Zweede 2006; Peña-Claros *et al.* 2008b). Unfortunately, despite decades of discussions, multitudes of workshops, and numerous research and demonstration projects, a misunderstanding of what constitutes improved forest management persists at all levels, from forest workers to company executives (Ezzine de Blas and Ruiz-Perez 2008).

Inefficiency and waste in the forest and along the market chain

In selectively logged tropical forests, an estimated 20% of the volume of harvestable timber is either lost on the forest floor or abandoned and left to rot because of inefficient and wasteful bucking practices (Sist and Bertault 1998; Holmes *et al.* 2002). Typically, less than 50% of the total volume of wood from a tree reaches the mill. In most tropical sawmills, the yield of sawn timber from log is often only 35%. Drying the sawn wood translates into an additional 10% volume loss. Finally, when the dried lumber is processed into furniture or other products, the yield is generally less than 70%. Yields in the plywood sector are marginally better because mills are more efficient and because they only process choice logs.

Failure to recognise and deal with wildfire

The large-scale but low intensity wildfires that burn through the understories of millions of hectares of tropical forests in some years are a major source of greenhouse gas (GHG) emissions (Barber and Schweithelm 2000; Nepstad *et al.* 2001; Alencar *et al.* 2004). The amounts of carbon emitted vary substantially from year to year, but emissions continue for several years afterwards as damaged trees die off and contribute to the burgeoning fuel loads. Once a forest has burned, it is much more likely to burn in the future because burned out understories are more combustible, drier, hotter, and windier. Pasture grasses that invade burned areas further increase the likelihood of fires (Parsons 1972; Nepstad *et al.* 2001).

Remote sensing technologies are available to detect and monitor fires (Giglio *et al.* 2008), but forest managers need to know how and when to intervene. Because of the slow progress, low flame heights, and low apparent intensities of understory fires, even experienced foresters often underestimate their long-term effects. For example, in 1995, an otherwise dedicated forest manager in lowland Bolivia took no action when notified of a fire because he believed the impacts would be inconsequential. Two years later the burned area had lost most of its small trees, many of the large trees suffered heartrots and hollows, and the entire area was badly vine infested (Pinard *et al.* 1999). Now, 14 years later, the canopy in the burned area is still open, there is little sound timber, and African pasture grasses have spread into the forest from abandoned roads. On a larger scale, failure to contain fires in 1999 -- even though government officials, forestry concession owners and the media had up-to-date information from satellite images – resulted in 12 million hectares of lowland Bolivia being burned including half the city of Ascension de Guarayos.

Policies for improving forest management, reducing emissions, and enhancing carbon stocks

If we accept that sustainable forest management practices are only likely to be adopted where effective enforcement of regulations is coupled with financial incentives, then the case for REDD funding is clear. The challenge is to find effective, efficient, and equitable ways to retain and enhance carbon stocks that also deliver other co-benefits.

Foster third party certification

The advent of voluntary, third party certification, especially the Forest Stewardship Council (FSC) programme, is a new direction in the long history of attempts to improve tropical forest management (Auld *et al.* 2008). Certification has its detractors, and the mechanism is not flawless, but FSC does take into account social, ecological, and economic considerations and so avoids some of the shortfalls of previous policies (the Tropical Forestry Action Plan and the International Tropical Timber Organization's Year 2000 Objective). The main difference between certification and other interventions is that certification makes use of market forces to improve forest management. While the anticipated 'green premiums' from certification were initially overstressed, forest managers are becoming aware that certification substantially increases their market access. Policies that link verified carbon emissions reductions with certification of timber and other forest products would take advantage of natural synergies.

To the extent that certification has already improved tropical forest management, the question concerning potential policy interventions is what limits the effectiveness of certification? Ultimately, budget constraints explain why many forests, particularly many community-managed forests, are not yet certified (Ebeling and Yasué 2009). It is likely but not yet adequately documented that certified forests retain and sequester more carbon, provide more non-timber forest products, and support more biodiversity than uncertified tropical forests (Subak 2002; Levin *et al.* 2008). Certified forests are probably also more resilient in the face of climate change (Guariguata *et al*. 2008). Overall, supporting certification would seem like an effective and efficient use of REDD+ funding.

Certification programmes that promote better forest management and carbon sequestration have limitations other than scarcity of funding. One problem is that illegal operators, who cause much of the degradation from poor logging, are unlikely to seek certification. Some firms also harvest timber without regard for the negative effects on residual stands because they do not expect to harvest the same area again. For these companies, the costs of improving efficiency through use of the full suite of RIL techniques (e.g., annual coupe selection and planned harvesting) are likely to outweigh the benefits. Furthermore, it is important to recognize that certification involves more than simply employing RIL techniques, which means that even some companies and communities that manage forests may well find the costs of certification too high. FSC is working to reduce certification costs for small and low intensity managed forests, particularly those managed by communities, but further subsidies as well as improved governance are needed. A REDD+ fund for certification and certification audits could at least provide the needed fiscal incentives.

Require use of reduced-impact logging (RIL) techniques

Regulations requiring forest managers to use reduced-impact logging (RIL) techniques would be a major step forward in sustainable forest management and would substantially reduce carbon emissions from logged forests. Putz *et al.* (2008b) estimated that a switch to RIL in forests legally managed for timber harvesting would reduce global carbon dioxide emissions by 0.58 Gt per year. Post-logging silvicultural treatments would likely double this benefit and control of illegal logging would double it again.

One reason why loggers have not adopted RIL techniques is that, contrary to the findings from Brazil published by Holmes *et al.* (2002), RIL is not always more profitable than conventional logging. In the RIL-Sabah Project (Pinard and Putz 1996), for example, loggers complained that yields from RIL sites were substantially lower because RIL disallowed harvesting on steep slopes and in riparian buffer zones (Healey *et al.* 2000). The cost savings that accrue to loggers as well as the carbon savings enjoyed by society come mainly from better harvest planning (e.g., designation of annual allowable cuts on the basis of volume or area), directional felling, and low impact yarding techniques. In other cases, such as described by Holmes *et al.* (2002), avoiding the loss of logs was the biggest short-term financial benefit to loggers. The recommended changes in forest management practices that lead to increases in timber recovery translate into less risk of leakage, especially where RIL guidelines restrict logging in riparian buffer zones and on steep slopes (Schwarze *et al.* 2002).

Longer term benefits of RIL practices accrue to forest owners, long-term concession holders, and climate conscious citizens around the world because RIL-logged stands recover more quickly than those logged conventionally. Recent studies of post-RIL forest recovery suggest that the long-term carbon benefits of RIL are being substantially underestimated (Box 1).

Box 1. Carbon-neutral logging in a Malaysian rainforest: reduced collateral damage fosters rapid recovery

Michelle Pinard

Industrial-scale experimental implementation of RIL in old growth dipterocarp forest in Sabah demonstrated substantial carbon benefits from controlling damage (Pinard and Putz 1996). In this tall, heavily stocked forest, selective logging according to RIL guidelines retained, on average, 86 Mg ha^{-1} more carbon in living biomass than nearby forest logged using conventional logging practices (CL). Just thirteen years after logging, and in startling contrast to our predictions (Pinard and Cropper 2000), carbon in above ground biomass had returned to pre-harvest levels in RIL areas. In contrast, no recovery in carbon stocks was observed over the same period in CL areas (Lincoln 2008). While this case study demonstrates that selective logging can be carbon neutral over a very short period, the carbon savings associated with RIL depend on a variety of factors.

The CL *vs*. RIL carbon differential depends both on how bad conventional practices are, and on how well RIL is implemented. At our site, CL typically killed between 40% and 60% of the trees in the residual stand, a proportion that RIL reduced by more than half. Another practice that was a somewhat unique and possibly critical component of our RIL treatment was the cutting of all woody vines one year prior to harvest. Although blanket cutting was costly and probably had at least short-term negative impacts on wildlife, it reduced logging damage and post-harvest vine infestations. Fifteen years post-logging, the felling gaps in the RIL areas had generally closed, whereas about 45% of felling gaps in CL areas were dominated by tall herbs and vines (Tomlinson 2009).

Carbon savings with RIL also depend on whether harvesting restrictions influence overall timber yields. In our study, although average harvest intensities were similar in areas logged by the two methods, about 45% of the RIL areas were not logged because of legal restrictions on skidding on slopes exceeding 35 degrees. This foregone timber raised concerns about leakage because of the risk than any shortfall in timber from the RIL area might be harvested from elsewhere, a concern that would presumably be addressed by national-level carbon accounting. Ironically, our carbon estimates were conservative because we used conventional, single entry logging as the baseline instead of the repeated re-logging and conversion to plantations that dominated the landscape outside the project area.

Harvest intensity is important because, at very high intensities, some forests will be degraded even if harvested with care (Sist *et al.* 1998). At our site, harvest intensity was relatively high (54 to 175 m^3 ha^{-1} ;Pinard and Putz 1996) but, because many future crop trees in RIL areas survived logging and grew rapidly after being released from competition, rates of post-logging recovery of timber and biomass were very high. In contrast, and to our surprise, even undamaged trees in the CL areas experienced high mortality rates throughout the 13-year recovery period, and recruitment was balanced by mortality, accounting for the lack of carbon accumulation (Lincoln 2008).

RIL at the stand level has the potential to reduce emissions substantially. But forest management also has to be considered at the landscape level. Significant carbon savings from reducing the wastage of wood wastage and using less fuel consumption can be made by planning harvesting well and training crews appropriately. Scaling up such stand level practices to the landscape level has even greater benefits. At the national level, and as a prerequisite for setting national carbon emission baselines, planning means designating a 'permanent forest estate' that delineates and maintains both production and protected areas. In production forests, logging should be prohibited or strictly controlled in High Conservation Value Forests (HCVFs), riparian buffer zones, steep slopes, and other areas that are ecologically fragile or otherwise valuable. Within logged areas, maximum allowable harvesting volumes and minimum cutting cycles should be based on actual forest yield data. Once the annual coupes have been demarcated, accurate topographic maps need to be drawn up showing roads and harvesting patterns. While these recommendations are not new, they are seldom followed, which leaves a great deal of room for REDD+ additionality. Compliance is more likely than ever because improved remote sensing techniques coupled with hand-held global positioning system (GPS) tools means that it is possible to monitor compliance with government land-use rules quite cheaply. In community managed forests, more labour intensive monitoring can also be very effective (see Chapter X).

Train forest workers and reward them appropriately

Given how little it costs to train an experienced forest worker in RIL techniques, the continuing degradation of forests because of lack of training is unfortunate. Irrespective of the ancillary benefits of training, such as safer working conditions, more retention of biodiversity, and better protection of riparian areas, REDD investors will still need estimates of the carbon benefits derived from training forest workers in RIL.

Box 2: Training needs for RIL and improved forest management

Mark Schulze, Marco Lentini, and Johan Zweede

When applied in good faith by competent crews, RIL substantially reduces the harmful effects of selective timber harvesting on forest structure, carbon stocks and other ecosystem attributes (Johns *et al.* 1996; Bertault and Sist 1997; Pinard and Cropper 2000; Putz *et al.* 2008a). Ignoring the qualifications in the above assertion – good faith and competence – imperils the entire effort to promote better forest management as a mechanism to reduce emissions from degradation. RIL is not a switch that is flipped on by policy makers or the presidents of timber companies; it is an approach to planning, harvesting, and post-harvest operations that demands detailed knowledge and skills at all levels of an organization and often requires a cultural change in the forest sector. Moreover, effective monitoring and incentive schemes, essential to ensuring RIL is applied in good faith (Macpherson 2007), require well-trained staff at all levels in the government agencies responsible for enforcing environmental regulations (Johns *et al.*, 2008).

Recent policy developments in many tropical countries favour sound forest management (e.g., Tieguhong and Betti 2008; Tomaselli and Hirakuri 2008; Banerjee *et al.* 2009). These policies also create needs for qualified professionals that are staggering in scale. For example, if Brazil's vast network of public production forests (Verissimo *et al.* 2002; Zarin *et al.* 2007) is to contribute substantially to national REDD targets, then 27 000 to 33 000 trained forestry professionals will be needed (Schulze *et al.* 2008; Lentini *et al.* in press). In contrast, over the past 15 years fewer than 5000 Brazilians received hands-on training in forest management (J. Zweede unpublished). Such disparities between supply and demand for qualified forestry professionals are the norm across the tropics (Durst *et al.* 2006), and have been identified as a key factor in the slow adoption of RIL (Putz *et al.* 2000; Pokorny *et al.* 2005; Sabogal *et al.* 2005).

The history of forest management training initiatives in countries like Brazil, Guyana, and Indonesia provides grounds for both optimism and concern. In Brazil, a training initiative started in 1995 has played a key role in generating interest and capacity in RIL (Dykstra and Elias 2003). Virtually every FSC-certified operation in the Brazilian Amazon can be linked to this initiative. In spite of the steadily increasing demand for training, widespread recognition of the value of practice-based training and the low cost per worker ($500-1000), funding has been sporadic and piecemeal, and at levels well below that required to meet demand. For example, the current training capacity in Brazil is no more than 500 people per year while the need for training is one order of magnitude larger (Schulze *et al.* 2008). Similarly, only 700 Guyanese have been trained in RIL techniques; one person for every 20 000 ha of state production forest (TFF, 2008). In Indonesia, various initiatives have provided training to staff in just 30 out of 200 operating forest concessions. Fortunately, a recent surge in funding, if sustained, will allow a dramatic increase in staff training (A. Klassen personal communication). It is clear that there are ways for countries to meet daunting training challenges. Less clear is whether policy makers and funding agencies appreciate fully the connection between investment in training and successful implementation of forest policies.

Anyone who can lift a chainsaw can fell even a large tree, but in addition to strength and dexterity, experience and training are needed to do it safely and in such a way as to minimise damage to other trees. To estimate the carbon benefits of RIL training, we first assume that from the average tree (2 m^3 of merchantable wood) the RIL-trained feller leaves 0.1 m^3 less wood in the stump. Use of good felling techniques results in less damage to valuable future crop trees (FCTs) and minimises butt log splits and the risk of the log breaking upon impact (a saving of another 0.2 m^3 of harvestable wood). The feller also tops the log (severs it below the crown) and bucks it into manageable and merchantable sections. Trained fellers top trees and buck logs in ways that maximise utilisation (assume a 0.1 m^3 advantage per tree). We further assume that the density of the avoidable waste of 0.4 m^3 is 0.5 Mg/m^3 and that 50% of this biomass is carbon. This means that the average carbon benefit per tree felled by a trained worker is 0.2 Mg. If we assume that this carbon, delivered to the mill and not left on the forest floor, is worth $5/Mg on a carbon market and that a trained worker fells 10 trees a day, the investment of $1000 of REDD+ money in training will be paid off in carbon retention in just 100 days. The estimated payback period does not take into account reductions in collateral damage from directional felling. Nor does it consider improvements to the physical welfare of workers, lower fuel consumption by the skidders, quicker regrowth (Box 1), or increased forest resilience and resistance to fire. But the estimate does give an idea of the cost effectiveness of training just one worker in the production chain. And from the feller's perspective, given that the International Labour Organization (ILO 1990) ranks felling among the most dangerous profession in the world, receiving training that reduces the likelihood of injury or death is the ultimate social co-benefit.

Remuneration systems for forest workers need to reward those who apply these best harvesting practices. Payment systems that include a fixed monthly salary, a piece rate bonus and a reward dependent on work quality would motivate workers at little additional cost. Such incentives are needed even where RIL practices benefit logging contractors and forest owners so as to assure that the benefits are shared by forest workers (Applegate *et al.* 2004)

Control wildfires

Protocols for monitoring fires in real time, methods for notifying relevant authorities, and the capacity to deploy motivated, trained and equipped fire fighters need to be implemented. As most of the forest fires that do so much damage in the tropics are slow-moving ground fires, the equipment needs are modest. However, even when information on the locations of fires is available, remoteness and difficult access are still major problems to be overcome (Box 3).

Box 3. Forest fires in the Amazon: short-term individual benefits *vs.* long-term societal costs

Ane Alencar and Ricardo Mello (IPAM- Amazon Institute for Environmental Research, Brazil)

Fire is the least expensive and most broadly used method of clearing land and converting forest biomass into soil nutrients for pastures and crops in the tropics. Fire is used also to control weeds and to reinvigorate palatable pasture grasses. Even if beneficial for farmers over the short run, intensification of deforestation and burning impose long-term costs on individuals and society. Deforestation is associated with both forest fragmentation and an increase in ignition sources, two important elements of forest susceptibility to fire (Alencar *et al.* 2004). Coupled with global and regional climate change, these effects reduce the fire resistance of intact tropical forests. Even after a single, low-intensity understory fire, forests become more fire prone. The risk of large fires increases during droughts when canopy cover decreases, fuel loads increase as leaves are shed, and even the forest interiors dry out. In extreme droughts, such as during the El Niño of 1997 and 1998, the standing forest area burned by forest fires in the Amazon was at least double the area deforested generating an additional committed 0.7 Pg of CO_2 emissions – assuming a density of 100 tonne C/ha and 50% tree mortality (Alencar *et al.* 2006).

Wildfires cause direct losses in Amazonian Brazil estimated to vary between US$22 and US$42 million per year. The health costs alone represent more than US$10 million during ENSO years (Mendonça *et al.* 2004). But these fires have a cost that is more insidious and longer lasting than the cost of carbon emissions, smoke-induced respiratory problems, airport closures, infrastructure destruction, biodiversity losses and reductions in profits from crop and cattle production. This additional cost is that the high risk of fire constrains adoption of sustainable land-use practices, such as reduced-impact logging and cultivation of perennial crops, since both require long-term investments.

Fortunately, wildfires can to a large extent be controlled by motivated communities using well-established methods. A study of 28 rural communities in Para State indicated good cause for substantial motivation; small farmers lost 18% of their income to fires in 2004 (Mello and Pires 2004). By implementing fire control measures such as opening fire breaks and coordinating fire crews, these losses were reduced by 75% at a cost to the farmers of only 7% of their income. The benefits from the fire control measures varied, but included increases in carbon stocks of up to several tonne per hectare. The study indicates that it is possible to reduce fire-induced forest degradation in cost-effective ways that do not preclude a farmer's use of fire.

The social equity and ancillary benefits of controlling forest fires are substantial and varied. Human health benefits from avoiding high concentrations of particulates and other pollutants released by forest fires, especially those generated by smouldering combustion. Preventing large quantities of fire-generated aerosols from reducing regional rainfall also benefits society. From a biodiversity perspective, controlling forest fires has exceptional benefits, except where fires are part of the natural regime (e.g., savannas and woodlands).

Given the carbon consequences of fires in tropical forests, REDD funds could be used to improve real time satellite detection and monitoring of fires. Training in fire fighting would also translate into carbon savings if trained, motivated crews had the wherewithal to get to fire lines quickly. Not least, there is a need for networks of plots to monitor both immediate carbon losses from fires and to estimate further losses as injured trees die. For these, standardised protocols should be adopted. Unfortunately, adopting fire control as part of REDD+ is currently unlikely because 2009, in contrast to 1997-1998 when extensive fires closed airports and shut down businesses across the tropics, has not been a big year for fires. If COP-15 were to take place during a fire year, the case for fire control as part of REDD+ would be more compelling.

Develop incentives to enhance carbon stocks in logged, burned, and otherwise degraded forests

A wide range of methods are available for restoring degraded forests. A start could be made by stopping the causes of degradation and letting forests regenerate on their own. This approach could progress to actively managing degraded areas to accelerate regeneration and growth. Both methods are appropriate for most of the 60% of tropical forests that were degraded in the latter half of the 20th Century – about 1084 million ha (FAO 2006). For example, a REDD+ restoration intervention to encourage natural recovery might control illegal logging, promote reduced-impact logging, lower logging intensities, reduce damage from grazing animals, and prevent wildfires. This approach has been successful in Costa Rica and Puerto Rico where deforested areas recovered their old growth biomass and species richness after only 30–40 years (Letcher and Chazdon 2009). A more active approach involves accelerating regeneration and growth by controlling species that compete with natural regeneration or by augmenting regeneration with planted seeds, seedlings, or cuttings. Across the tropics there are many successful examples of these more active treatments (Peña-Claros *et al.* 2008a; Villegas *et al.* 2009).

A major constraint on restoration is lack of funding, but fortunately, some interventions are cost effective in terms of carbon benefits. For example, for a few dollars per hectare, the growth rates of trees that sequester large amounts of carbon and hold carbon for a long time can often be doubled by clearing vines and overtopping less enduring trees that compete with them (Wadsworth and Zweede 2006; Villegas *et al.* 2009). Restoring more degraded stands, by assisting natural regeneration is low in cost and often results in substantial gains in terms of carbon and biodiversity (Dugan *et al.* 2003). Where natural regeneration is not an option, enrichment planting and other reforestation methods, while expensive, can also yield carbon gains.

Increase security of tenure and resource access for forest owners and concessionaires

Secure tenure for communities or private firms, as well as secure long-term access for concessionaires, serve to promote good management. For example, in a study of 80 forest commons in 10 tropical countries, Chhatre and Agrawal (2009) found that carbon stocks increased with the size of the forest, the authority to make decisions locally, and community ownership. Similarly, in areas with extensive forest and limited public infrastructure, forest concessions can help maintain forests while providing social benefits (Karsenty *et al*. 2008, but see Merry *et al*. 2003). Community ownership or secure private tenure seem to be prerequisites for good management but are not sufficient to prevent owners from acting in ways that impose social costs on others. For one thing, illegal logging does not stop when forests are held in common (Kaimowitz 2003; Honey-Rosés 2009) nor does tenure security guarantee good forest stewardship (Gould *et al.* 2006). Therefore, in addition to secure tenure, other regulations and incentives will be required to promote better forest management.

Increase efficiency of the sector through appropriate taxation

Wood wastage along the market chain from the forest to the final product results in part from the design of tax and royalty systems. When levies on harvested timber are collected far from felling sites, timber that does not make it to the point where royalties are assessed is not accounted for and can be wasted. To maximise recovery of felled timber, royalties should be assessed as close to the stump as possible. Ideally, taxes should be calculated on the basis of gross standing volumes (clear bole volumes of standing trees). This approach would encourage concession holders to minimise wastage due to poor felling, poor bucking, and otherwise inefficient log utilization. A somewhat less favourable alternative would be to calculate royalties on site according to the volume felled.

Develop market-based instruments to improve management

In addition to or instead of taxes, various market-based instruments (MBI) could be used to internalise social costs, convert benefits into private returns, and stimulate changes in the economic behaviour of entrepreneurs (Richards and Moura Costa 1999). Forest certification is a familiar MBI (see above), but performance bonds can also promote better management. These refundable bonds are deposited in a government account at the beginning of the concession period. If harvesting is executed in accordance with RIL and other standards, the bonds are gradually returned to the concessionaires. Fines for non-compliance are deducted. The bonds provide an incentive to shift from short-term exploitation to sustainable forest management. Performance bonds can also compensate, at least in part, for the discounting challenge to long-term management. By ensuring that concessionaires receive income gradually and towards the end of the cutting cycle, bonds also influence potential returns from logging new areas, roughly in line with the net value of a second harvest (Richards 2000).

Conclusions

The carbon benefits and co-benefits of better forest management, wildfire control, and ecological restoration will be promoted by secure long-term access to the resource. This security can be in the form of durable concessions, usufruct rights, or private or community ownership. To promote better management, forest regulations should be based on realistic estimates of forest productivity (i.e., harvestable timber and carbon stocks) so that harvesting regulations (volume limits, cutting cycles) sustain profits as well as carbon and timber stocks. Professionalising the forest work force by providing training will boost workers' capacity to implement good forestry practices, for which they should be appropriately rewarded. Finally, market-based incentives for better forest management, particularly third party forest product certification, should be a critical component of REDD+ programmes. Such incentives would help to reduce carbon emissions, improve worker safety, protect biodiversity, and maintain other ecosystem services.

Improvements in the ways forested areas are managed are only likely if there is the right mix of incentives and enforcement. Given the benefits from transforming exploitation into management, a REDD+ mechanism could provide the much needed financial and technical support for improved forest management, wildfire control, and enhanced carbon uptake through restoration of degraded areas.

References

Alencar, A., Nepstad, D. and Vera-Diaz, M.C. 2006 Forest understory fire in the Brazilian Amazon in ENSO and non-ENSO years: area burned and committed carbon emissions. Earth Interactions 10 (Paper 6).

Alencar, A., Solorzano, L. and Nepstad, D.C. 2004 Modeling forest understory fires in an eastern Amazonian landscape. Ecological Application 14: 139-149.

Applegate, G., Putz, F.E. and Snook, L.K. 2004 Who pays for and who benefits from improved timber harvesting practices in the tropics: lessons learned and information gaps. CIFOR, Bogor, Indonesia.

Asner, G.P., Knapp, D.E., Broadbent, E.N., Oliveira, P.J., Keller, M. and Silva, J.N. 2005 Selective logging in the BrazilianAmazon. Science 310: 480–482.

Auld, G., Gulbrandsen, L.H. and McDermott, C.L. 2008. Certification schemes and the impacts on forests and forestry. Annual Review of Environment and Resources 33: 187-211.

Barber, C.V. and Schweithelm, J. 2000 Trial by fire: forest fires and forestry policy in Indonesia's era of crisis and reform. World Resources Institute, Washington, DC.

Banerjee,O., Macpherson, A.J. and Alavalapati, J. 2009 Towards a policy of sustainable forest management in Brazil: a historical analysis. The Journal of Environment and Development 18: 130-153.

Bertault, J-G. and Sist, P. 1997 An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. Forest Ecology and Management 94: 209–218.

Cerutti, P.O., Tacconi, L. and Nasi, R. 2008 Sustainable forest management in Cameroon needs more than approved forest management plans. Ecology and Society 13(2): 33. http://www.ecologyandsociety.org/vol13/iss2/art33/, accessed 31 October 2009

Chhatre, A. and Agrawal, A. 2009 Trade-offs and synergies between carbon storage and livelihood benefits from forest commons. IFRI Working Paper no. W091-01, University of Michigan, Ann Arbor, MI.

Chhatre, A. and Agrawal, A. 2009 Trade-offs and synergies between carbon storage and livelihood benefits from forest carbon. Proceedings of the National Academy of Sciences (USA) doi/10.1073/pnas.0905308106.

Chomitz, K. 2006 At loggerheads? Agricultural expansion, poverty reduction, and environment in tropical forests. The World Bank, Washington, DC.

Dugan, P.C., Durst, P.B., Ganz, D.J. and Mckenzie, P.J. 2003 Advancing assisted natural regeneration (ANR) in Asia and the Pacific. FAO Regional Office for Asia and the Pacific, Bangkok.

Durst, P.B., McKenzie, P.J., Brown, C.L. and Appanah, S. 2006 Challenges facing certification and eco-labelling of forest products in developing countries. International Forestry Review 8: 193-200.

Dykstra, D. and Elias. 2003 RIL becomes real in Brazil. International Tropical Timber Organization Tropical Forest Update 13/4.

Ebeling, J. and Yasué, M. 2009 The effectiveness of market-based conservation in the tropics: Forest certification in Ecuador and Bolivia. Journal of Environmental Management 90: 1145-1153.

Ezzine de Blas, D. and Ruiz Pérez, M. 2008 Prospects for reduced impact logging in Central African logging concessions. Forest Ecology and Management 256: 1509-1516.

de Graaf, N.R. 2000 Reduced impact logging as part of the domestication of neotropical rainforest. International Forestry Review 21: 40–44.

Food and Agriculture Organization of the United Nations (FAO). 2006 Global forest resources assessment 2005. Food and Agriculture Organization of the United Nations, Rome.

Gibbs, H.K., Brown, S., Niles, J.O. and Foley, J.A. 2007 Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environmental Research Letters 2: 045023.

Giglio, L., Csiszar, I., Restás, A., Morisette, J.T., Schroeder, W., Morton, D. and Justice, C.O. 2008 Active fire detection and characterization with the advanced spaceborne thermal emission and reflection radiometer (ASTER). Remote Sensing of Environment 112: 3055-3063.

Gould, K.A., Carter, D.R. and Shrestha, R.K. 2006 Extra-legal land market dynamics on a Guatemalan agricultural frontier: Implications for neoliberal land policies. Land Use Policy 23: 408-420.

Guariguata, M.R., Cornelius, J.P., Locatelli, B., Forner, C. and Sánchez-Azofeifa, G.A. 2008 Mitigation needs adaptation: Tropical forestry and climate change. Mitigation and Adaptation Strategies for Climate Change 13: 793-808.

Healey, J.R., Price, C. and Tay, J. 2000 The cost of carbon retention by reduced impact logging. Forest Ecology and Management 139: 237–255.

Holmes, T.P., Blate, G.M., Zweede, J.C., Pereira Jr., R., Barreto, P., Boltz, F. and Barch, R. 2002 Financial and ecological indicators of RIL logging performance in the eastern Amazon. Forest Ecology and Management 163: 93–110.

Honey-Rosés, J. 2009 Illegal logging in common property forests. Society and Natural Resources 22: 916-930.

International Labour Organization (ILO). 1990. Occupational safety and health in forestry. International Labour Organization, Geneva, Switzerland.

Johns, J.S., Barreto, P. and Uhl, C. 1996 Logging damage during planned and unplanned logging operations in the eastern Amazon. Forest Ecology and Management 89: 59–77.

Johns, T., Merry, F., Stickler, C., Nepstad, D., Laporte, N. and Goetza, S. 2008 A three-fund approach to incorporating government, public and private forest stewards into a REDD funding mechanism. International Forestry Review 10: 458-464.

Kaimowitz, D. 2003 Forest law enforcement and rural livelihoods. International Forestry Review 5: 199-210.

Karsenty, A., Drigo, I. G., Piketty, M-G. and Singer, B. 2008 Regulating industrial forest concession in Central Africa and South America. Forest Ecology and Management 256: 1498-1508.

Lentini, M., Schulze, M. and Zweede, J. In press. Os desafios ao sistema de concessoes de florestas publicas na Amazonia. Ciencia Hoje.

Letcher, S.G. and Chazdon, R. L. 2009 Rapid recovery of biomass, species richness, and species composition in a forest chronosequence in northeastern Costa Rica. Biotropica 41: 608-617.

Levin, K., McDermott, C. And Cashore, B. 2008 The climate regime as global forest governance: can reduced emissions from deforestation and forest degradation (REDD) initiatives pass a 'dual effectiveness' test? International Forestry Review 10: 538-549.

Lincoln, P. 2008 Stalled gaps or rapid recovery – the influence of damage on post-logging forest dynamics and carbon balance. PhD Thesis, University of Aberdeen, Scotland.

Macpherson, A.J. 2007 Following the rules: a bioeconomic policy simulation of a Brazilian forest concession. Ph.D. Dissertation, University of Florida, FL.

Mello, R. and Pires, E.C.S. 2004 Valoração econômica do uso de técnicas de prevenção e controle de queimadas em cenários de produção familiar na Amazônia: Um estudo de caso em comunidades rurais de Paragominas, Pará, Brasil. IPAM/CSF/CI, Belém, Brazil.

Mendonça, M.J.C., Vera-Diaz, M.C., Nepstad, D., da Motta, R.S., Alencar, A., Gomes, J.C. and Ortiz, R.A. 2004 The economic cost of the use of fire in the Amazon. Ecological Economics 49: 89-105.

Merry, F.D., Amacher, G.S., Pokorny, B., Lima, E., Scholz, I., Nepstad, D.C. and Zweede, J.C. 2003 Some doubts about concession in Brazil. International Tropical Timber Organization Tropical Forest Update 13: 7-9.

Nepstad, D., Carvalho, G., Barros, A.C., Alencar, A., Capobianco, J.P., Bishop, J., Moutinho, P., Lefebvre, P., Silva, U.L. and Prins, E. 2001 Road paving, fire regime feedbacks, and the future of Amazonian forests. Forest Ecology and Management 154: 395-407.

Parsons, J.J. 1972 Spread of African pasture grasses to the American tropics. Journal of Range Management 25: 12-17.

Pearce, D., Putz, F.E. and Vanclay, J. 2002 Sustainable forestry: panacea or pipedream? Forest Ecology and Management 172: 229-247.

Peña-Claros, M., Peters, E.M., Justiniano, M.J., Bongers, F., Blate, G.M., Fredericksen, T.S. and Putz, F.E. 2008a Regeneration of commercial trees species following silvicultural treatments in a moist tropical forest. Forest Ecology and Management 255: 1283-1293.

Peña-Claros, M., Fredericksen, T.S., Alarcon, A., Blate, G.M., Choque, U., Leaño, C., Mostacedo, B., Pariona, W., Villegas, Z. and Putz, F.E. 2008b Beyond reduced-impact logging: silvicultural treatments to increase growth rates of tropical trees. Forest Ecology and Management 256: 1458-1467.

Pinard, M.A. and Cropper, W.P. 2000 Simulated effects of logging on carbon storage in dipterocarp forest. J Appl Ecol 37: 267-283.

Pinard, M.A., Putz, F.E., Tay, J. and Sullivan, T.E. 1995 Creating timber harvest guidelines for a reduced-impact logging project in Malaysia. Journal of Forestry 93: 41-45.

Pinard, M.A. and Putz, F.E. 1996 Retaining forest biomass by reduced logging damage. Biotropica 28: 278-295.

Pinard, M.A., Putz, F.E. and Licona, J.C. 1999 Tree mortality and vine proliferation following a wildfire in a subhumid tropical forest in eastern Bolivia. Forest Ecology and Management 113: 201-213.

Pokorny, B., Sabogal, C., Silva, J.N.M., Bernardo, P., Souza, J. and Zweede, J. 2005 Compliance with reduced-impact harvesting guidelines by timber enterprises in *terra firme* forests of the Brazilian Amazon. International Forestry Journal 7: 9-20.

Putz, F.E., Dykstra, D.P. and Heinrich, R. 2000 Why poor logging practices persist in the tropics. Conservation Biology 14: 951-956.

Putz, F.E. and Redford, K.H. 2009 Dangers of carbon-based conservation. Global Environmental Change doi10.1016/j.gloenvcha.2009.07.005.

Putz, F.E., Zuidema, P., Pinard, M.A., Boot, R.G.A., Sayer, J.A., Sheil, D., Sist, P., Elias, and Vanclay, J.K. 2008a Improved tropical forest management for carbon retention. PLOS Biology 6: 1368-1369.

Putz, F.E., Sist, P., Fredericksen, T.S. and Dykstra, D. 2008b Reduced-impact logging: challenges and opportunities. Forest Ecology and Management 256: 1427-1433.

Rice, R.E., Gullison, R.E. and Reid, J.W. 1997 Can sustainable management save tropical forests? Scientific American 276: 44-49.

Richards, M. 2000. Can sustainable tropical forestry be made profitable? The potentials and limitations of innovative incentive mechanisms. World Development 28: 1001–1016.

Richards, M. and Moura Costa, P. 1999 Can tropical forestry be made more profitable by internalising the externalities? Natural Resource Perspectives 46: 6.

Saatchi, S.S., Houghton, R. A., Dos Santos Alvala, R.C., Soares, J.V. and Yu, Y. 2007 Distribution of above ground live biomass in the Amazon basin. Global Change Biology 13: 816–837: doi: 10.1111/j.1365-2486.2007.01323.x.

Sabogal, C., Pokorny, B., Silva, N., Bernardo, P., Massih, F., Boscolo, M., Lentini, M., Sobral, L. and Veríssimo, A. 2005 Manejo florestal empresarial na Amazônia Brasileira. Restrições e oportunidades para a adoção de boas práticas de manejo. Final Report. CIFOR/EMBRAPA, Belém.

Sasaki, N. and Putz, F.E. 2009 Critical need for new definitions of "forest" and "forest degradation" in global climate change agreements. Conservation Letters doi: 10.1111/j.1755-263X.2009.00067.x.

Schulze, M., Grogan, J. and Vidal, E. 2008 Technical challenges to sustainable forest management in concessions on public lands in the Brazilian Amazon. Journal of Sustainable Forestry 26: 61-75.

Schwarze, R., Niles, J.O. and Olander, J. 2002 Understanding and managing leakage in forest-based greenhouse-gas-mitigation projects. Philosophical Transactions of the Royal Society of London 360: 1685-1703.

Sist, P. and Bertault, J-G. 1998 Reduced impact logging experiments: impact of harvesting intensities and logging techniques on stand damage. *In*: Bertault, J-G. and K. Kadir, K. (eds) Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan, 139-161. CIRAD-Forêt, Montpellier, France.

Sist, P. Nolan, T., Bertault, J-G. and Dykstra, D.P. 1998 Harvesting intensity versus sustainability in Indonesia. Forest Ecology and Management 108: 251-260.

Smith, J., Colan, V., Sabogal, C. and Snook, L. 2006 Why policy reforms fail to improve logging practices: the role of governance and norms in Peru. Forest Policy and Economics 8: 458-469.

Subak, S. 2002. Forest certification eligibility as a screen for CDM sinks projects. Climate Policy 2: 335-351.

Sunderlin, W., Hatcher, J. and Liddle, M. 2008. From exclusion to ownership? Challenges and opportunities in advancing forest tenure reform. Rights and Resources Initiative. Washington, DC.

Tacconi, L. 2007. Illegal logging: law enforcement, Livelihoods and the timber trade. Earthscan, London.

Tieguhong, J.C. and Betti, J.L. 2008 Forest and protected area management in Cameroon. International Tropical Timber Organization Tropical Forest Update 18/1.

Tomlinson, F. 2009 Do harvesting impacts determine patterns of non-forest vegetation in dipterocarp forest in Sabah 15 years post-logging? MSc Thesis, University of Aberdeen, Scotland.

Tropical Forest Foundation (TFF). 2008 Tropical Forest Foundation News Spring 2008. http://www.tropicalforestfoundation.org/newsletters/newsletter2008_spring.pdf. (16 Aug 2008).

Veríssimo, A., Cochrane, M.A. and Souza Jr., C. 2002 National forests in the Amazon. Science 297: 1478.

Villegas, Z., Peña-Claros, M. Mostacedo, B. Alarcon, A. Licona, J.C., Leaño, C. Pariona, W. and Choque, U. 2009 Silvicultural treatments enhance growth rates of future crop trees in a tropical dry forest. Forest Ecology and Management 258: 978-985.

Wadsworth, F.H., Zweede, J.C. 2006. Liberation: acceptable production of tropical forest timber. Forest Ecology and Management 233: 45–51.

Walters, B.B., Sabogal, C., Snook, L.K. and de Almeida, E. 2005. Constraints and opportunities for better silvicultural practice in tropical forestry: an interdisciplinary approach. Forest Ecology and Management 209: 3-18.