



Carbon benefits from avoiding and repairing forest degradation

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- 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 more achievable than ever 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 ongoing forest certification is fully utilised.

Introduction

International discussions about REDD+ have focused on deforestation, with little regard for the more damaging, but equally extensive, 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.* 2008b). Furthermore, forest degradation often enhances the likelihood of subsequent deforestation. Finally, and not least, in the interests of adaptation to climate change, loss of resilience in degraded forests is of great concern (Guariguata *et al.* 2008).

This chapter focuses on the carbon benefits arising from better forest management (i.e., training workers, planned harvesting and reduced-impact logging plus postharvest silvicultural treatments (RIL+)) and coordinating fire detection and suppression (fuel wood harvesting is discussed in Chapter 19). We also discuss options for restoring degraded forests to enhance the rate 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 at the expense of biodiversity, ecosystems services, and social welfare (Putz and Redford 2009).

Why is there 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.* 2003). In terms of the Von Thünen 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 agricultural frontiers, 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 2007). Under such conditions, loggers might gain by adopting some cost-cutting and better harvesting techniques (e.g., planned skid trails to reduce fuel consumption), but they would not gain from adopting better management techniques wholesale (Putz *et al.* 2008b). Many sustainable management practices are only likely to be adopted where effective enforcement of regulations is backed by financial incentives. This need means 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 2007c). That said, 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 created by authorities who do not understand the socio-ecological context in which they are to be implemented. 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. Consequently, forest managers are accustomed to operating in environments where 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 these are controlled by rural communities and indigenous groups (Sunderlin *et al.* 2008a). 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 one and 20 trees per hectare. Unfortunately, for every tree harvested by untrained and unsupervised fellers and machine operators working without detailed plans, some 10 to 20 others are severely damaged (Putz *et al.* 2008b; 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. Silvicultural treatments applied after logging, such as clearing competitive species from around future crop trees, can double rates of recovery (Peña-Claros *et al.* 2008a). Nevertheless, despite decades of discussions, dozens 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). 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 detect and suppress wildfires

The large-scale, but low intensity, wildfires that intermittently burn the understorey 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 understoreys are more combustible, drier, hotter and

windier. 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. Understorey fires typically progress slowly and burn with low flame heights and modest flame widths. Because of their low apparent intensities, even experienced forest managers can underestimate their long-term effects. Unfortunately, even low-temperature fires can damage large trees if they burn long enough. 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 had heart rots and hollows, and the entire area was badly infested with vines (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 – meant that more than 12 million hectares of lowland Bolivia were burned and half the city of Ascension de Guarayos was destroyed.

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. 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 (e.g., 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 promotes socially and environmentally beneficial market influences on forest management. While the anticipated 'green premiums' from certification were initially overstressed, forest managers are becoming aware that certification substantially increases their market access (Auld *et al.* 2008). 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 proven, that certified forests retain and sequester more carbon, provide more non-timber forest products, and support more biodiversity than uncertified tropical forests. They are probably also more resilient in the face of climate change (Guariguata *et al.* 2008). Thus, 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. 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 RIL techniques (e.g., annual coupe selection and planned harvesting) are likely to outweigh the benefits. Furthermore, it is important to recognise that certification involves more than simply improving efficiency through the use of RIL techniques, which means that even some companies and communities that manage forests well may 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 are needed. A REDD+ fund for certification and certification audits could provide the needed incentives.

Require use of reduced impact logging techniques

Regulations requiring forest managers to use RIL techniques would be a major step forward in sustainable forest management and would substantially reduce carbon emissions from logged forests. Putz *et al.* (2008a) 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 double this benefit, and control of illegal logging would likely double it again.

One reason why loggers have not adopted RIL techniques is that, contrary to findings from Brazil (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 and the carbon savings to society, come mainly from better harvesting plans and from training workers in 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. Changes in forest management practices that lead to increases in timber recovery translate into less risk of leakage, especially where RIL restricts 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 regenerate 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 20.1).

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 wood wastage and using less fuel 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. Remote sensing 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 8).

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 20.1. 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 tonnes/ha more carbon in living biomass than nearby forests logged using conventional logging practices (CL). Just 13 years after logging, and in startling contrast to our predictions (Pinard and Cropper 2000), carbon in aboveground 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 v. 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 an unusual 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°. This foregone timber raised concerns about leakage because of the risk that 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 relogging 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 m³/ha; 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).

Box 20.2. Training needs for RIL and improved forest management

Mark Schulze, Marco Lentini and Johan C. 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.* 2008b). 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 organisation 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 on a huge 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, since 1994 fewer than 5000 Brazilians received hands-on training in forest management (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.* 2006).

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 (US \$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 of 200 operating forest concessions. Fortunately, a recent surge in funding, if sustained, will allow a dramatic increase in staff training (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 fully appreciate 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 m³ of merchantable wood) the RIL-trained feller leaves 0.1 m³ 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 m³ 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 and buck logs in ways that maximise utilisation (assume a 0.1 m³ advantage per tree). We further assume that the density of the avoidable waste of 0.4 m³ is 0.5 tonnes per m³ and that 50% of this biomass is carbon. This means that the average carbon benefit per tree felled by a trained worker is 0.1 tonnes. If we assume that this carbon, delivered to the mill and not left on the forest floor, is worth US \$5/tonne on a carbon market and that a trained worker fells 10 trees a day, the investment of US \$500 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. Neither does it consider improvements to the physical welfare of workers, lower fuel consumption by the skidders, quicker regrowth (Box 20.1) 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 professions 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 location of fires is available, remoteness and difficult access are still major problems to be overcome (Box 20.3).

Box 20.3. Forest fires in the Amazon: short-term individual benefits versus long-term societal costs

Ane Alencar and Ricardo Mello

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 also used 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 understorey 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 CO₂ emissions – assuming a density of 100 t 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 El Niño–Southern Oscillation (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 RIL 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 tonnes 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 significant and diverse. Human health benefits from avoiding high concentrations of particulates and other pollutants released by forest fires; emissions from slow moving or smouldering fires are much worse for human health than those from more intense fires. 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 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 in 2009 – in contrast to 1997–1998 when extensive fires closed airports, shut down businesses and caused huge losses across the tropics – fires have been few. If COP15 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 is 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 RIL, 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 accelerates 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.* 2008b; Villegas *et al.* 2009).

A major constraint to restoration is the 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 options, 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). Therefore, in addition to secure tenure, other regulations and incentives will be required to promote better forest management.

Increase sector efficiency 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 use. A somewhat less favourable alternative would be to calculate royalties on site according to the volume felled.

Develop incentive policies or 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, 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 noncompliance 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 toward the end of the rotation period, bonds also influence potential returns from logging new areas, roughly in line with the net value of a second harvest (Richards 2000).

Conclusion

The carbon benefits and co-benefits of better forest management, including wildfire control and forest restoration, will be promoted by secure long-term access to the resource. Secure access can be in the form of durable concessions, usufruct rights, or private or community ownership. 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 costs of transforming exploitation into management, a REDD+ mechanism could provide financial and technical support for 'pioneering' managers. These could be logging companies or communities that stop poor forest management and wildfires and enhance carbon uptake through restoration of degraded areas.