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## Improved Tropical Forest Management for Carbon Retention

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Negotiations leading up to an international climate change agreement to replace the Kyoto Protocol in 2012 include consideration of reduced emissions due to deforestation and degradation (REDD). This option has figured prominently in the “road map” toward such an agreement that was agreed upon during the 13<sup>th</sup> Conference of Parties to the United Nations Framework Convention on Climate change held in Bali in December 2007 ([www.unfccc.int](http://www.unfccc.int)). Most on-going discussions of REDD focus on tropical deforestation while the potential carbon saving from reduced forest degradation are mostly being disregarded [1,2]. Given that carbon losses due to degradation could be of the same magnitude as those from deforestation, this disregard is worrisome [3,4]. We show here that substantial reductions of global CO<sub>2</sub> emissions can be achieved by improving forest management in the tropics and argue that this cost-effective approach to mitigation should be included in the new climate change agreement.

Worldwide, a total area of 350 million hectares of tropical moist forests is designated as production forest [5], about a quarter of which is managed by rural communities and indigenous people [6]. These forests are mainly exploited for timber, and given growing timber demand and increased forest access, logging is likely to expand. Due to the high diversity of natural forests and limited markets for the timber of most tree species, loggers usually only harvest 1-20 trees

per hectare.

Unfortunately, for every tree logged in this selective manner, some 10-20 others are severely damaged by untrained fellers and machine operators working without the aid of detailed maps or supervision [7]. Numerous studies have demonstrated that with appropriate harvest planning of log extraction paths coupled with worker training in directional felling, 50% or more of this collateral damage can be avoided. Implementing these basic reduced-impact logging techniques, as we show below, could substantially reduce global carbon emissions from forest degradation.

We illustrate the carbon benefits of improved forest management with a large scale and long-term study in Malaysia [8]. In forests subjected to conventional logging, carbon emissions were over 100 tons  $t\ ha^{-1}$  (Fig. 1). In contrast, where improved harvesting practices were used, these initial losses were much lower, mainly due to reduced collateral damage. After 30 years, the typical period after which loggers are allowed to return to an area for the next harvest, carbon stocks in the forest with improved management are predicted to be at least 30  $t\ ha^{-1}$  higher than those in conventionally logged forest [9], and probably much higher. In a similar study in Amazonian Brazil where forests are logged much less intensively [10], the benefit of improved timber harvesting practices was estimated to be 7  $tC\ ha^{-1}$ . In both cases, improved management reduced carbon emissions by ~30% relative to conventional logging.

The potential global contribution of improved tropical forest management to carbon retention is substantial. Using information on intensities and intervals of logging, area of production forest [5], and the above figures on carbon loss, we estimated the global consequences of improved tropical forest management. We stress that this estimate is conservative insofar as we lacked information to scale up the carbon-retention effects of some practices in improved forest management (improved road planning, bridge construction, stream protection). Also, our estimate of the production forest area most likely under-represents the actual area where logging takes place.

Use of improved timber harvesting practices in the tropical forests designated for logging would retain at least 0.16  $GtCy^{-1}$  (Fig. 2). Most of the emission reductions from improved forestry will be from the more intensively logged forests in Asia, where emissions are largest. This reduced annual rate of carbon emissions is substantial. For comparison, the total amount of carbon emitted due to tropical deforestation is estimated to be 1.5  $Gt\ y^{-1}$  (or 20% of global anthropogenic emissions, ref 1). Thus, the potential for emissions reductions through improved forest management is at least 10% of that obtainable by curbing tropical deforestation.

Programs promoting global reductions in carbon emissions through improved forest management should easily satisfy the UNFCCC criteria for biomass projects ([www.unfccc.int](http://www.unfccc.int)). Given that improved forest management is currently practiced in <5% of tropical forests [5], the additionality criterion (i.e., the intervention has direct impacts on carbon emissions relative to the baseline) seems easily satisfied if carbon policy-motivated interventions actually result in changes in timber harvesting practices. In regards to “permanence” of the sequestered carbon (i.e., the time period over which the carbon is retained), the long intervals between timber harvests in well managed forests guarantee that benefits of protecting trees from avoidable damage is lasting. And, given that timber harvests under improved management continue at the same intensity and with similar or even higher financial yields as with the more destructive conventional logging, there is little threat of loggers employing their destructive practices elsewhere and hence causing “leakage” of the carbon benefits (i.e., there is no incentive from the intervention for participants to increase carbon emissions elsewhere).

During the negotiations leading to the Kyoto Protocol, improved forest management practices were dropped from consideration due to concerns about the feasibility and costs of monitoring. Since that time numerous field studies have demonstrated that forest carbon stocks can be measured with fair precision [7,8,10]. Of at least equal importance are the rapid recent improvements in remote sensing methodologies that should soon make it feasible to directly estimate forest carbon stocks from space [4,7]. Furthermore, the costs of monitoring forest carbon stocks and fluxes, both on the ground and through remote sensing, can be shared by the responsible government agencies, forest product certifiers, and REDD credit programs. Clearly, if REDD provides a true and strong economic incentive to improve timber harvesting in the tropics, it will be cost effective to solve any remaining technical difficulties.

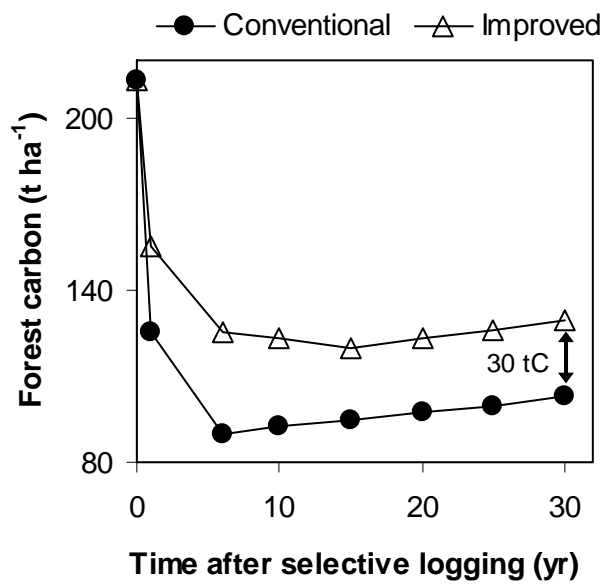
In addition to increased carbon retention, there are important other benefits from improving forest management. For example, by minimizing canopy opening, forest flammability decreases and shade-requiring wildlife and plants continue to thrive. Also, future timber yields are enhanced when fewer of the valuable trees are damaged and when careful planning of roads and trails minimizes erosion and maintains watershed functions. Finally, substantial occupational health and safety benefits can be achieved from training workers in one of the world’s most dangerous professions.

Incentives to retain more forest carbon through improved management would represent a big step towards sustainability in the vast area of tropical forests outside protected areas. Although many details on measuring, monitoring, and compensating carbon sequestering individuals, companies, communities, and governments need to be sorted out, reducing emissions of greenhouse gases from tropical forest degradation should be given a high priority in negotiations leading up to the new climate change agreement to be redacted in Copenhagen in 2009.

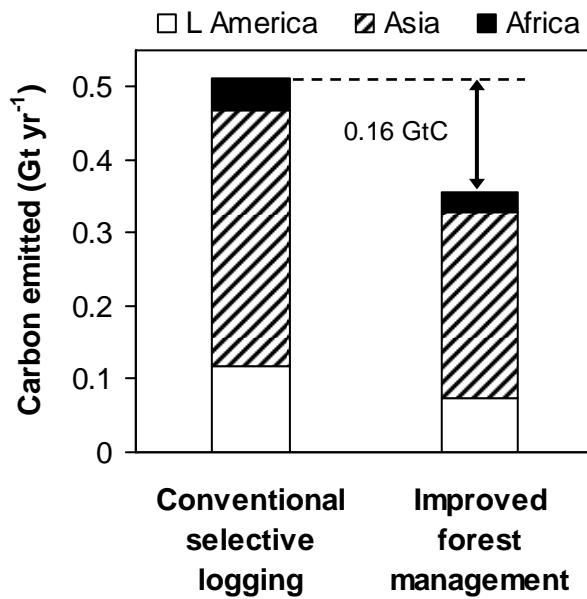
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**Figure 1.** Substantial Reductions in Carbon Loss from Improved Forest Management at Scales of a Hectare of Malaysian Forest (ref 7)



**Figure 2.** Annual Reductions in Global Carbon Emissions That Would Result from Adoption of Improved Tropical Forest Management Practices (ref 7)



## Supplementary Files

### Improved Tropical Forest Management for Carbon Retention

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#### **Improved forest management: from conventional logging (CL) to reduced-impact logging (RIL)**

Reduced-impact logging (RIL) can be defined as intensively planned and carefully controlled timber harvesting conducted by trained workers in ways that minimize the deleterious impacts of logging (S1). RIL in the tropics has a long history but benefited from advancements in Australia in the 1980s and wide dissemination of basic guidelines by FAO in the 1990s (S2) as well as by development of regional and national codes-of-logging-practice. Table S1 gives an overview of the major techniques included in RIL, and their effects on trees, forests, and carbon.

Table S1. A partial list of practices customary included in reduced-impact logging guidelines and their effects on forests and carbon retention (S1-S6).

Practice	Objective	Effect on forest <sup>a</sup>	Effect on carbon retention	Included in our calculations?
Planning of log landings	Reduce size and number of log landings	Substantial	Positive	No <sup>b</sup>
Planning of roads	Reduce length and area of trails	Substantial	Positive	No <sup>b</sup>
Construction of bridges, water culverts	Reduce water impoundments	Moderate	Positive	No <sup>b</sup>
Planning of skid trails	Reduce soil and tree damage	Large	Positive	Yes
Marking of future crop trees	Reduce tree mortality and damage	Substantial / Large	Positive	Yes
Directional felling	Reduce tree damage and increase volume recovery	Substantial	Positive	Yes
Liana cutting	Reduce collateral damage and gap size	Substantial	Positive	Yes

<sup>a</sup> Categories of effect: Moderate <25%; Substantial 25-50%; Large >50%

<sup>b</sup> Carbon retention effects can be large, if logging practices are poor (S7)

### **The effects of RIL on forests and carbon**

Research on RIL has flourished over the past two decades, with more than 200 publications on the topic in many countries located in all three major tropical forest areas. RIL has been particularly effective in reducing tree mortality and damage (Table S1). By reducing damage to the forest, the most commonly used RIL practices have positive effects on carbon retention. In addition, worker training substantially reduces risks, which is relevant insofar as the International Labour Organization reports that logging is among the world's most dangerous professions (S8).

### **Recent improvements in remote sensing methods for estimating forest carbon stocks**

The use of laser altimetry (lidar) in combination with now traditional passive remote sensing methods heralds great strides towards direct measurement of forest carbon from space or airborne units (S9).

### **Carbon emissions from conventional logging and RIL at the hectare scale**

We obtained carbon emissions from selectively logged forests from studies in Sabah, Malaysia (S5, S10) and Para, Brazil (S11-14). These studies are representative of the wide range of harvesting intensities and selective logging practices in the tropics. Commercial timber trees are abundant in SE Asian forests, leading to high logging intensities (~8-15 trees/ha, ~80-120 m<sup>3</sup>/ha), while in Latin America and Africa harvestable trees are scarcer and thus logging intensities are typically lower (~1-5 trees/ha, ~5-30 m<sup>3</sup>/ha).

Standing stocks of carbon in unlogged forests in both areas were calculated using field data on abundance and diameter of trees, allometric relations of trees, wood densities, abundance of non-woody plants, below-ground biomass, and biomass of woody debris and by assuming the carbon fraction of total dry mass to be 0.5. Resulting estimates of total carbon stocks in unlogged forests are 213 and 186 tC/ha for Malaysia (S5) and Brazil (S12), respectively, and are comparable to those from other studies (S14).

Both studies calculated carbon losses due to logging using field observations continuing up to 6 years after logging (timber volume removed, tree death, amount of woody debris, area cleared) (S5,S11,S13,S14), and simulation models of forest and carbon dynamics (using information on wood decay and tree growth rates) (S10,S12). The simulations allow estimation of carbon losses over several decades. In both studies, a comparison was made between conventional and reduced-impact logging (S10,S12).

Carbon losses due to selective logging at cycles (intervals) of 30 and 60 years decline substantially where reduced-impact logging (RIL) techniques are used (Table S2). Conventional logging leads to a carbon loss of as much as 50% in Malaysia whereas the losses estimated in Brazil (10-15%) are similar to those reported in other studies (5-20%, S16-18). RIL leads to

substantially smaller loss of carbon, reducing these losses by 28-42% depending on location and logging interval. We report carbon consequences for 30 y because this is currently the most frequently prescribed logging cycle in tropical forests (S19), and for 60 y as this lapse in time between harvests is more likely to sustain timber yields and otherwise allow for better forest recovery (S2, S20-S22). The combination of applying RIL and lengthening the logging cycle from 30 y to 60 y would lead to much greater reductions in carbon loss than either change alone. For clarity, only the 30-y cycle results are presented in the main text, as these are closest to current practices, and do not alter profit margins.

Table S2. Carbon stocks, losses, and retention in unlogged and logged tropical rain forests in Malaysia and Brazil. Carbon consequences of conventional logging (CL) and reduced-impact logging (RIL) are compared.

	Sabah, Malaysia (S5,S9)	Para, Brazil (S10-13)
Total carbon in unlogged forest (t ha <sup>-1</sup> )	213	186
Logging intensity (m <sup>3</sup> ha <sup>-1</sup> )	125	30
Carbon loss and retention with 30-y logging cycles		
- Loss from CL (t ha <sup>-1</sup> )	108	19
- Loss from RIL (t ha <sup>-1</sup> )	78	12
- Carbon retained due to RIL (t ha <sup>-1</sup> )	30	7
Carbon loss and retention with 60-y logging cycles		
- Loss from CL (t ha <sup>-1</sup> )	93	24
- Loss from RIL (t ha <sup>-1</sup> )	57	14
- Carbon retained due to RIL (t ha <sup>-1</sup> )	36	10

### Scaling up carbon emissions from conventional logging and RIL

We used the information from the two studies in Table S2 to estimate global carbon retention resulting from improved forest management. We used the extent of tropical production forests reported by ITTO (S19) in the three continents with tropical forests (Asia, Meso- and South America, Africa) to estimate of the total area of forest under selective logging. We assumed a 30-y logging cycle as this best represents regulations and practice in Latin America, Africa, and Asia (S19). We then used the two available studies on carbon loss in selectively logged forests (Table S2) to convert carbon losses from hectare to continent scales. As logging intensities in

Africa are comparable to those in Latin America, we used the results of the Brazil study there. We assumed that carbon impacts of logging at the continent-average intensity (30, 30, and 80 m<sup>3</sup>/ha for Americas, Africa and Asia, respectively) were adequately estimated from the two available studies (S5, S12). Given that logging damage increases little with harvests >80 m<sup>3</sup>/ha (S1), the estimates we use from in the Malaysia study (125 m<sup>3</sup>/ha harvested) are not expected to overestimate damage. We converted carbon loss values during one logging cycle (Table S2) to annual values by assuming that 1/30 of the area is logged annually, as is common in multi-cyclic silvicultural systems. Although the only two available studies on carbon impact of selective logging yield comparable results for carbon savings due to RIL as a proportion of carbon loss through conventional logging, the extrapolated figures for global-scale effects should be interpreted cautiously. Nevertheless, our estimates of carbon retention are likely conservative if long-term recovery trajectories of RIL and conventional logging strongly differ due to arrested regeneration in the latter, compared to fast recovery in the former. Our estimates are also conservative insofar as they do not include the effects of forest clearance for poorly planned and unnecessary roads and log landings in forests with conventional logging (Table S1). Given that the data suggest that cutting cycles should be much longer than the typical 30 years, we include calculations of the carbon consequences forest management with 60-y cycles (S2, S20-23).

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