Accepted by *iForest - Biogeosciences and Forestry* (2010)

# Approaches to Classifying and Restoring Degraded Tropical Forests for the Anticipated REDD+ Climate Change Mitigation Mechanism

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**Keywords**: Assisted natural regeneration, biodiversity, climate change agreement, forest restoration, REDD-plus, reduced-impact logging, silviculture

**Type of article**: Policy Perspectives

**Number of words**: 194 words in abstract, 4974 words (all inclusive)

**Number of reference**: 56

**Number of tables and figures**: 1 table, 3 color figures, **Supplementary Material**: 1

**Running Title**: Restoring Degraded Tropical Forests

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## Abstract

Inclusion of improved forest management as a way to enhance carbon sinks in the Copenhagen Accord of the United Nations Framework Convention on Climate Change (December 2009) suggests that forest restoration will play a role in global climate change mitigation under the post-Kyoto agreement. Although discussions about restoration strategies often pertain solely to severely degraded tropical forests and invoke only the enrichment planting option, different approaches to restoration are needed to counter the full range of degrees of degradation. We propose approaches for restoration of forests that range from being slightly to severely degraded. Our methods start with ceasing the causes of degradation and letting forests regenerate on their own, progress through active management of natural regeneration in degraded areas to accelerate tree regeneration and growth, and finally include the stage of degradation at which re-planting is necessary. We argue that when the appropriate techniques are employed, forest restoration is cost-effective relative to conventional planting, provides abundant social and ecological co-benefits, and results in the sequestration of substantial amounts of carbon. For forest restoration efforts to succeed, a supportive post-Kyoto agreement is needed as well as appropriate national policies, institutional arrangements, and local participation.

## 1. Introduction

Tropical forests support much of the Earth's biological diversity and contribute substantially to the global economy, to local human welfare, and to the global carbon budget. Based on 109 case studies from across the tropics (TEEB Climate Issues Update 2009 as cited in Sukhudev 2010), if all the ecosystem services provided by tropical forests were paid for, they would generate about \$11.1 trillion year$^{-1}$ (\$6,120 ha$^{-1}$ *1807 million ha), nearly equivalent to the European Union's GDP in 2009. Unfortunately, the capacity of tropical forest to provide these services is reduced each year by deforestation (Lambin et al. 2003, FAO 2010) as well as by degradation principally due to uncontrolled logging (Gaston et al. 1998, Asner et al. 2009, Asner et al. 2010, FAO 2006, Tacconi 2007) and fires (Nepstad et al. 1999, Siegert et al. 2001). With regard to degradation, at least 392 million ha, or 20% of the total area of humid tropical forests, were logged during 2000–2005, and about 50% of standing humid tropical forests retained 50% or less cover as of 2005 (Asner et al. 2009, FAO 2010). The limited data available on carbon emissions due to forest degradation suggest that they double the 1.5–2.2 PgC yr$^{-1}$ released by deforestation (Asner et al. 2010, Gullison et al. 2007, Houghton 2003, Putz & Nasi 2009). Furthermore, deforestation and forest degradation also affect 89% of all threatened birds, 83% of threatened mammals, and 91% of threatened plants (www.iucn.org).

There is growing recognition of and increasing interest in generating carbon credits through reducing emissions from deforestation and forest degradation with enhancement of carbon sinks (REDD+), as evident by the recognition in the Copenhagen Accord adopted at the 15th Conference of the Parties (COP15) to the United Nations Framework Convention on Climate Change (UNFCCC 2009) in December 2009. Unfortunately, most of the international attention has focused on avoided deforestation (Kindermann et al. 2008, Gullison et al. 2007) and enhancement of carbon sinks through reforestation and afforestation (Thomas et al. 2010) either within or outside the framework of the Kyoto Protocol. Much less attention has been paid to halting and reversing forest degradation through restoration, interventions that in addition to increased forest carbon stocks have many collateral benefits including the improved capacity of forest lands to provide other ecosystem services, support biodiversity, and contribute to social welfare. With negotiations about REDD+ intensifying, an urgent issue now is how to restore degraded forests in socially viable, environmentally acceptable, and economically cost-effective manners. Restoration strategies should be a key element of any REDD+ agreement, and therefore such strategies need to be clarified. Here we focus on the causes of degradation, propose a classification scheme that reflects the severity of degradation, and point to ways to restore degraded forests that are appropriate for the classes proposed.

## 2. Defining "Forest" for the Purposes of Reversing Forest Degradation

For the purposes of elucidating forest degradation, we adopt the UNFCCC's definition of "forest" and the linked definitions of "deforestation" and "forest degradation" (Marrakesh Accord, Decision 11/CP.7) in full recognition of their limitations (Sasaki & Putz 2009, Hance 2010, Putz & Redford 2010). Although we are particularly concerned about the lack of reference to species composition in this definitions, we take a "forest" to be an area of > 0.05 ha with tree crown cover >20% with a "tree" defined as a plant with the capacity to grow to >3 m tall. It follows then that "forest degradation" is the loss of trees and their carbon stocks down to the point that an area no longer qualifies as being forested, at which point the area is "deforested." We further define "restoration" as management activities that help degraded forests recover their lost carbon stocks, biodiversity, and capacities to provide other goods and environmental services.

## 3. Restoration Strategies and Approaches

Tropical forests are degraded in ways that reduce tree cover and carbon stocks principally by indiscriminate logging (Asner et al. 2006, Asner et al. 2010), fires (Page et al. 2002, Aragão & Shimabukuro 2010), shifting cultivation (Lawrence 2005), and harvesting trees for charcoal production (Ahrends et al. 2010). To counter the effects of degradation, whatever the causes and regardless of the degrees, tree planting is often prescribed (Lamb et al. 2005, Chazdon 2008). Without denying the value of tree planting where seed sources have been eliminated and degradation is otherwise severe, there are other approaches to forest restoration that are often more cost-effective and that engender fewer ecological concerns (Ganz & Durst 2003, Letcher & Chazdon 2009, Peña-Claros et al. 2008, Shono et al. 2007a, Vieira et al. 2009, Villegas et al. 2009, Zimmerman et al. 2007). By categorizing forests on the basis of degrees of degradation (Fig. 1), we can select from among these approaches with more assurance of success in terms of low financial costs, better biodiversity conservation, and broad social and environmental benefits.

**Fig. 1 here**

To facilitate communication about restoration strategies for forests modified from their primary, old growth, or mature condition ($P_0$ in Fig. 1), we define the following arbitrary set of states. Forests in state A are slightly degraded but retain some trees above the minimum diameter at breast height (DBH) for legal harvesting (DBH limits for tropical countries are provided in the Supplementary Materials). Forests in state B are moderately degraded due to having lost their legally harvestable trees but retain many that are just smaller than the minimum cutting diameter (for legal harvest). Forests in state C are highly degraded insofar as they contain only trees much smaller than the minimum cutting diameter. Finally, forests in state D are critically degraded insofar as they have few residual trees of any size (but enough for the area to still be considered "forest"; Fig. 2).

**Fig. 2**

To provide rough estimates of the carbon stocks lost from forests degraded from point A to point D, data from Cambodia (Kao & Iida 2006, Kim Phat et al. 2000), Indonesia (Sist & Saridan 1998), Brazil (Wellhöfer 2002, Nascimentoa & Laurance 2002), and Panama (Chave et al. 2003) suggest restorable losses of above-ground carbon stocks of 26.3 to 173.0 MgC $ha^{-1}$ with an average of 112.4 MgC (Fig. 3 and Table 1). Depending on the degree of degradation, ecological characteristics of the residual species, needs and preferences of critical forest stakeholders, availability of funds, and accessibility, any of three general approaches to restoration can be appropriate, presented below in reference to these categories of degraded forest.

**Fig. 3**

**Table 1**

### 3.1. Restoring Slightly Degraded Forest (SDF, $P_0$ to A to $P_A$)

SDF refers to areas where timber harvesting was restricted to the legally permitted fraction of trees and only occurred in accordance with government-specified minimum cutting cycles or at longer intervals. The degradation is due to regulated harvests being more intensive and more frequent than the forest can biologically sustain, at least in the absence of silvicultural treatments, as well as due to harvesting by untrained and inadequately supervised workers operating without the aid of adequate harvest plans. The consequent reductions in carbon stocks and high-value tree species are represented by the transition from points $P_0$ to A.

To restore SDF, we propose reductions in logging intensities, avoidance of timber harvesting from steep slopes and other environmentally sensitive areas, and lengthening of cutting cycles, as appropriate, coupled with the use of reduced-impact logging techniques and liberation treatments of future crop trees in the residual stand. These changes in management practices that serve  to reduce wood waste and logging damage, and to increase the growth of future crop trees are termed reduced-impact logging plus silviculture (RIL+; refer to Table SM1 in the Supplementary Materials  for explanations of terms and impacts of various logging practices in the tropics). RIL+ involves worker training, harvest planning, site preparation, directional felling, and use of appropriate equipment for log yarding. Liberation treatments might include mechanical girdling and/or killing with herbicides of non-commercial trees that overtop future crop trees, plus vine cutting to accelerate the recruitment and growth of trees that have the capacity to grow to be large. Such treatments can accelerate average tree growth by 9–27% for all tree species, and by 50–60% for future crop trees (Peña-Claros et al. 2008, Villegas et al. 2009); application of such treatments to a selectively logged forest in Amazonian Brazil doubled the annual rate of above-ground biomass recovery from 0.16 to 0.33 Mg C $ha^{-1}$ $yr^{-1}$ (see SM for calculations) during at least the initial 6 years following logging (Wadsworth & Zweede 2006). It is important to note, however, that in Indonesia, the benefits of RIL for the residual stand disappeared where the logging intensity was >8 trees $ha^{-1}$ (Sist et al. 2003). Reduced felling intensities benefits not only regeneration and growth of the residual stand, but also the long-term ecological sustainability of forest management operations.

### 3.2. Restoring Moderately Degraded Forest (MDF, $P_0$ to B to $P_B$)

In MDF, more commercially high-value trees are harvested than authorized, and excessively damaging logging practices are employed. Unfortunately, failure to enforce forest management regulations is commonplace in the tropics (Gustafsson et al. 2007) and results in substantial but avoidable losses in forest carbon stocks (down to point B on Fig. 1). These logging practices result in substantial losses of commercially high-value timber species (Uryu et al., 2008) and substantial canopy opening, which renders forests susceptible to further degradation by drought and fires. MDF still contains some intermediate size trees, some of which are reproductively mature, and some large trees with defective stems, but carbon stocks are reduced by half of that in SFD (Table 1). MDF requires human intervention to protect the intermediate size trees and accelerate their growth. Forests in this category could be restored by active liberation and other silvicultural treatments to enhance the growth of future crop trees (B to A’), or more passively by preventing pre-mature re-entry logging and the continued use of poor logging practices (A’ to $P_B$).

### 3.3. Restoring Highly Degraded Forest (HDF, $P_0$ to C to $P_C$)

In HDF even trees smaller than the legal-size limit (see Table SM2) and reproductively mature trees of low financial value were harvested presumably in response to strong demand for timber and fuelwood coupled with weak governance. Due to substantial canopy opening caused by excessive and repeated tree harvesting, such forests are very susceptible to further degradation by fire or grazing coupled with invasion by fire-favoring graminoids. HDF is assumed to still contain some small residual forest trees, but carbon stocks are further reduced from those in MDF (Table 1). Restoration of HDF requires the cessation of the causes of degradation (B' to A'') followed by intensive liberation treatments to stimulate the growth of trees with the capacity to grow to large sizes. In forests allocated for timber production, one goal is to bring the degraded forest back to a point where there are some sound trees larger than the legal limit for harvesting (C to B'); if natural regeneration and seed trees of heavily exploited species are too scarce, enrichment planting with native species might be justified.

### 3.4. Restoring Critically Degraded Forest (CDF, $P_0$ to D to $P_D$)

CDF corresponds to areas that barely qualify as forest under the UNFCCC's definition and that are at the ecological threshold from which unassisted recovery is unlikely (Lamb et al. 2005). CDFs have been stripped of most trees by over-harvesting of timber and fuelwood collection, and are often burned, overgrazed, and dominated by lianas, shrubs, giant herbs, graminoids, or other non-arboreal species, both native and exotic. At point D, the risk of further degradation and transformation to non-forest land is generally very high (du Toit et al. 2004). CDF still contains some small trees, but carbon stocks are reduced to <20% of SDF values (Table 1). Initial restoration of such areas begins with stopping the causes of degradation and allowing natural recovery processes to proceed, but such processes often need to be accelerated by various forms of more active restoration. The restoration strategies recommended for moving from point D to C' generally involve replanting (e.g., Lamb et al. 2005, Chazdon 2008, and Shono et al. 2007b), which is costly and therefore unlikely to be widely implemented. Based on various studies across the tropics (e.g., Ganz & Durst 2003, Shono et al. 2007a), "assisted natural regeneration" is likely to be more cost-effective than replanting, thus making large-scale implementation more feasible. This approach might include fire management, grazing restrictions, suppressing the growth of invasive and fire-favoring graminoids (e.g., *Imperata cylindrica, Pennisetum purpureum*, and *Urochloa maxima*), protecting naturally regenerated native tree species, weeding, fertilizing, and, if necessary, inter-planting of native or even exotic nitrogen-fixing trees. Depending on geographic locations and forest conditions, another possible approach is to apply an "agro-successional" restoration approach that has proven effective with forest-dependent communities that farm (Vieira et al. 2009). Agro-successional approach involves the use of a "taungya" system in which native tree species are inter-planted with annual crops; after two or so food crops have been harvested, the trees come to dominate the area and the farmers move to another area to repeat the process. Eventually, thinning may be needed to accelerate the growth of desired individuals, thus speeding the transition from point C' to B". The residues from pruning and thinning might be used for forage or fuelwood by nearby communities. With increasing forest stature, stopping the causes of degradation continues to be important as the recovery proceeds from B" to A'". Eventually, during the final restoration phase (A'" to $P_D$), RIL+ treatments become appropriate.

## 4. Making these Strategies Work

A major constraint on the success of restoration interventions is the continued availability of funding, but some of the options we describe are not expensive to implement. For example, the switch from excessively destructive to reduced-impact logging reportedly ranges from having slight negative (Tay et al. 2002) to large positive effects on profits from timber harvesting (Holmes et al. 2002). Depending on geographical location, season, and equipment, costs for liberation treatments by girdling of unwanted trees are likewise modest; in Bolivia they were estimated at \$0.21–1.04 per tree or about \$5.08–25.17 $ha^{-1}$ (Ohlson-Kiehn et al. 2006; this assumes girdling of 24.2 competing trees $ha^{-1}$ on average, based on Wadsworth & Zweede 2006). The costs of restoration using assisted natural regeneration techniques are far less than enrichment planting and other conventional plantation development techniques because the costs of propagating, raising, and planting seedlings are avoided (Ganz & Durst 2003, Shono et al. 2007a). Average costs of ANR in three sites in the Philippines are approximately \$579 ha$^{-1}$ compared to \$1,048 ha$^{-1}$ for conventional reforestation methods (Durst et al. 2010). Furthermore, forests resulting from assisted natural regeneration are more biologically diverse and provide more benefits to local people than plantations. As restoration proceeds, more long-term benefits from ecosystem services and employment are expected, especially where efforts are financially supported by either the voluntary carbon market or funds from a future REDD+ agreement. Financial support for the latter is pledged at \$3.5 billion annually between 2010 and 2012 (Grassi et al. 2010) and more is likely for an expected post-Kyoto implementation period between 2013 and 2020. Successful implementation of payments for ecosystem services for restoring forests in Costa Rica (Pagiola 2008, Calvo-Alvarado et al. 2009) and in South America (Turpie et al. 2008) provide evidence in support of the financial viability of our proposed approaches to restoration.

Effective and efficient monitoring and verification are essential to any global program that includes halting degradation and restoration among possible climate mitigation strategies. The framework we propose fits well with the latest techniques in satellite monitoring that allow direct estimation of canopy loss, recovery, and closure at a range of logging intensities (Asner et al. 2006, Curran & Trigg 2006, GOFC-GOLD 2009). Moreover, the next generation of biomass-sensitive satellite sensors will soon be launched, with many more planned (GOFC-GOLD 2009), which further supports the proposed strategy. Due to technological advancements and the availability of free data, the costs for monitoring carbon stocks and emissions are already as low as \$0.06 ha$^{-1}$ in Madagascar, and \$0.08 ha$^{-1}$ in Amazonian Peru (Asner et al. 2010)

## 5. Conclusions

Restoring degraded tropical forests has a huge potential for mitigating global climate change by enhancing carbon stocks. Among the approaches discussed, the first is to stop the causes of degradation and allow forests to regenerate on their own. The second approach is to accelerate tree regeneration and growth through application of any of a variety of silvicultural treatments. The third general approach is to plant seeds or seedlings in natural or artificial gaps, a process often referred to as enrichment planting. To promote widespread implementation of these strategies under REDD+ initiatives, appropriate incentives, policies, institutional arrangements, and local participation are required. Since restoration takes time, long-term political commitments by participating countries will be required. REDD+ funded forest restoration will contribute to sustainable development and help secure the ecosystem services upon which billions of people depend.

## Acknowledgements:

We thank D. R. Foster., B. A. Colburn, K. Tanaka, B. B. Eav, M. Suwa, D. Orwig, and S. Seng for helpful comments, and S. Ouk, S. Ty, and E. Cadaweng for photos. N. Sasaki was supported through the Harvard Forest's Charles Bullard Fellowship in Forest Research for Advanced Research. G. Asner was supported by the Gordon and Betty Moore Foundation.

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## Figures and Captions

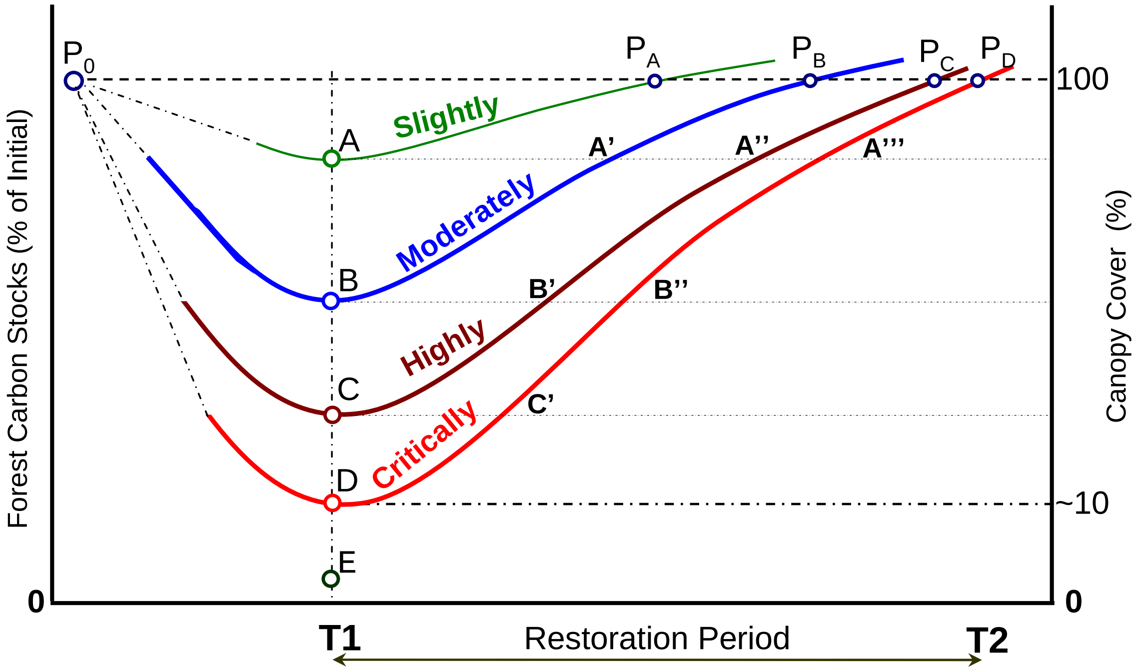

**Fig. 1** – Schematic diagram of different states of forest degradation and time courses for restoration. The right and left Y-axes represent different degrees of degradation expressed qualitatively as carbon stocks and percent canopy cover, respectively.

**Legend for Fig. 1.**

$P_0$: Pre-harvest level of primary or old growth forest.

A: Only authorized trees are harvested.

B: All trees larger than the minimum diameter for cutting are harvested.

C: All marketable trees are harvested.

D: No longer forest according to forest definition adopted by the UNFCCC in 2001 (Marrakesh Accord, Decision 11/CP.7).

E: Deforested.

D to E is eligible for reforestation or afforestation under the Clean Development Mechanism (CDM) if deforested prior to 1989 or 1940, respectively.

A to D: degradation.

D to E: deforestation.

T1 -T2: restoration period.

Negotiations to include avoiding deforestation and degradation (AE) are underway.

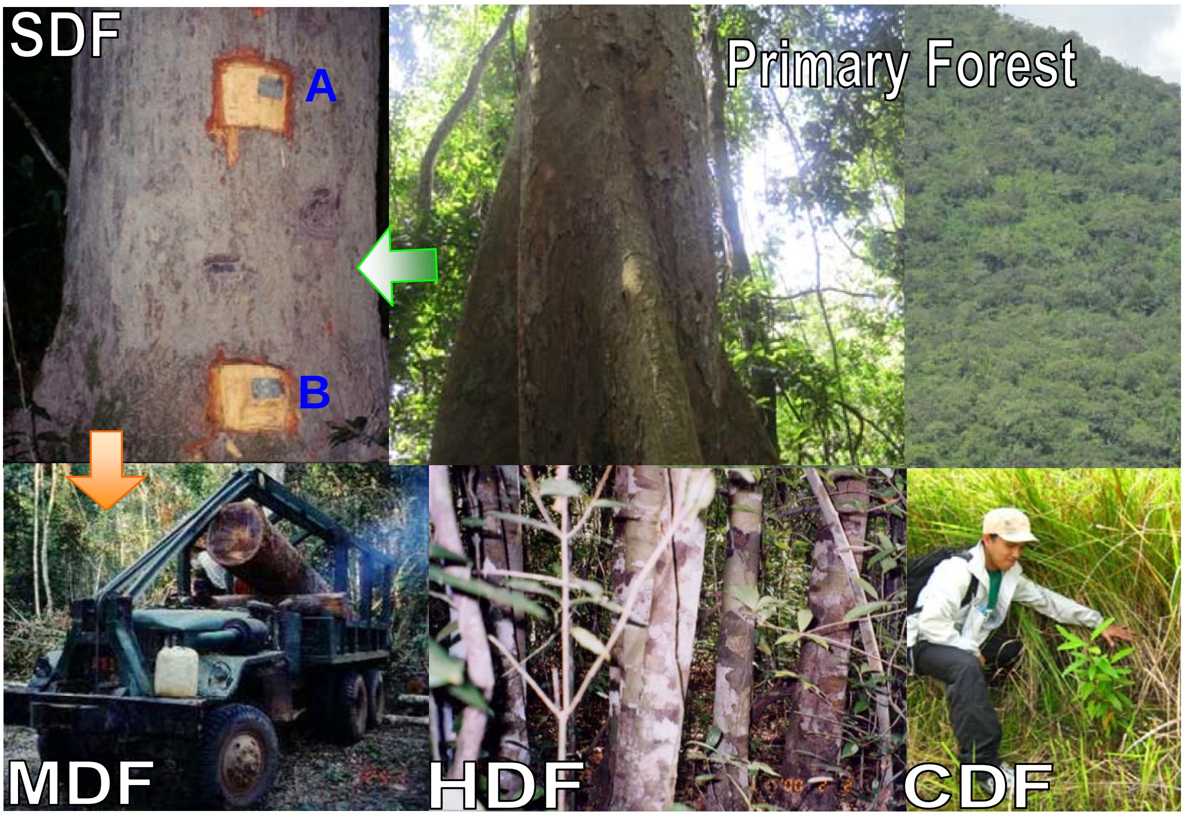

**Fig. 2 –** Primary and degraded natural forests. Points A & B are tags on a mature tree that was authorized for felling in Cambodia. Tree species, DBH, block, and coupe numbers are noted on each tag. To be considered legal, the feller must cut this tree between the two tags. All felled trees without such tags are considered illegal.

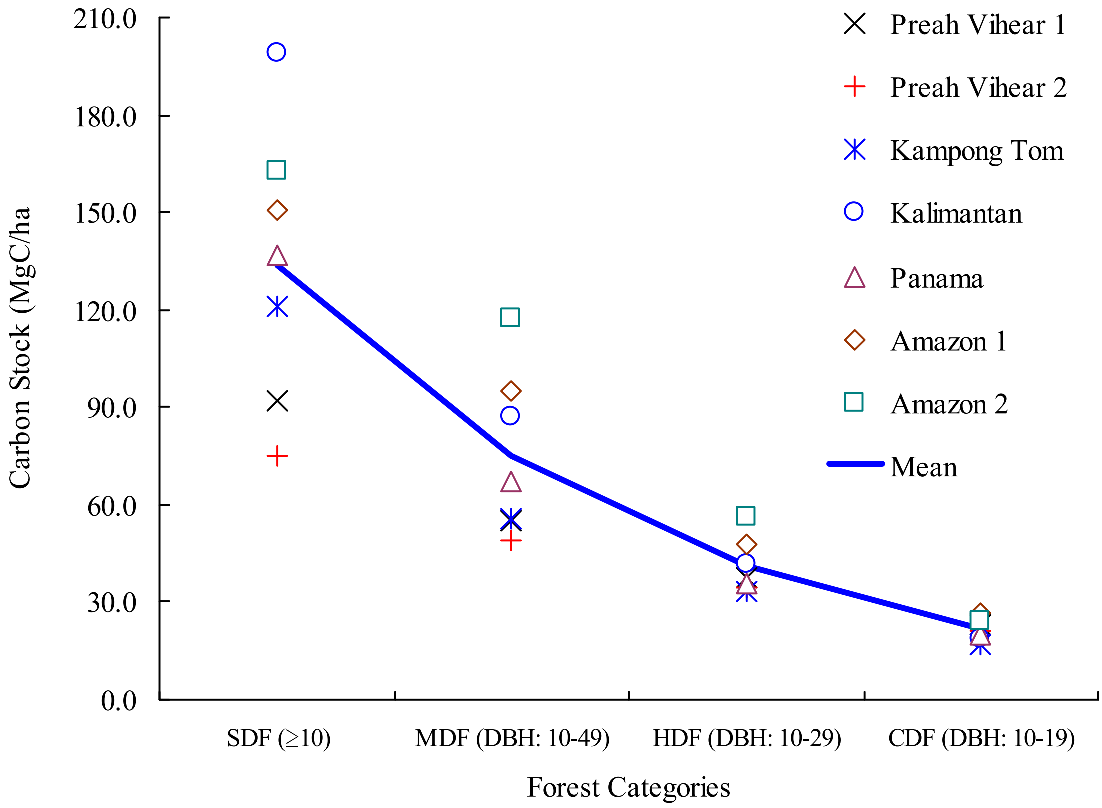

**Fig. 3** – Above-ground carbon stocks in slightly (SDF), moderately (MDF), highly (HD), and critically (CDF) degraded forests. If CDF can be gradually restored back to the SDF, more carbon will be sequestered and stored in the forest

Note 1: due to variations in carbon stocks in various forest types across the tropics, here in the Fig. 3, we assume that SDF, MDF, HDF, and CDF contains trees with DBH≥10 cm, 10-49 cm, 10-29 cm, and 10-19 cm, respectively. With these assumptions, carbon stocks in relevant degraded forests are shown in the Fig. 3 above.

Note 2: Data for Preah Vihear 1 (unlogged forest in Preah Vihear province, Cambodia), Preah Vihear 2 (logged forest in Preah Vihear province, Cambodia) were adopted from Kao and Iida (2006); data for forests in Kampong Tom province, Cambodia were adopted from Kim Phat et al. (2000); data for forest in Kalimantan (East Kalimantan, Indonesia) were taken from Sist and Saridan (1998); data for forests in Panama were adopted from Chave et al. (2003); data for Amazon 1 and Amazon 2 were adopted from Wellhöfer (2002) and Nascimentoa and Laurance (2002), respectively.

## Table 1

Table 1 – Average above-ground carbon stocks in tropical forests and percentages

| **Category** | **SDF** | **MDF** | **HDF** | **CDF** |
|---|---|---|---|---|
| **C. Stocks** | (DBH≥10 cm) | (DBH: 10-49 cm) | (DBH: 10-29 cm) | (DBH: 10-19 cm) |
| **Above-ground carbon Stocks (MgC ha$^{-1}$)** | | | | |
| MIN | 75.3 | 49.0 | 33.1 | 17.1 |
| MAX | 199.4 | 117.2 | 56.6 | 26.3 |
| MEAN | 134.0 | 75.2 | 41.0 | 21.6 |
| **Percentage of above-ground carbon stocks (%)** | | | | |
| MIN | 100.0 | 65.1 | 44.0 | 22.7 |
| MAX | 100.0 | 58.8 | 28.4 | 13.2 |
| MEAN | 100.0 | 56.1 | 30.6 | 16.1 |

Note: Data in table 1 were derived from two sites in Brazil (Wellhöfer 2002, Nascimentoa & Laurance 2002), three sites in Cambodia (Kao & Iida 2006, Kim Phat et al. 2000), one site in Indonesia (Sist & Saridan 1998), and one site in Panama (Chave et al. 2003)

# Supplementary Material (SM)

Sasaki et al. Effective Restoring Strategies for Degraded Tropical Forests under the Anticipated REDD+ Mechanism

Table SM1 Forest management and logging practices in the tropics

| Description | Uncontrolled or Anarchic Logging | Reduced-Impact Logging (RIL) | Reduced-Impact Logging plus silvicultural treatments (RIL+) |
|---|---|---|---|
| History | Intensified about 50 years ago (Nicholson 1958, Putz et al. 2000) | Early 1980s (Ward & Kanowski 1985) | Early 2000s (Peña-Claros et al. 2008) |
| Common practices | Unplanned logging with untrained crews, concentrated felling | Properly planned, trained, and supervised logging with site preparation, directional felling, use proper equipment | Additional to RIL, girdling or arboriciding unwanted trees, vine cutting |
| Logging damage to residual stands | 48.4–56.0% (see Sasaki & Putz 2009) | 28.0–30.5% (see Sasaki & Putz 2009) | |
| Wood waste proportional to felling intensity | 20.0–46.2% (see Sasaki & Putz 2009) | 0–26.2% (see Sasaki & Putz 2009) | |
| Growth rates | Rapidly declining (Asner et al. 2005, 2006) | Leading to sustained yield (Palmer & Synnott 1992) | Growth rates of future crop trees is 50–60% higher compared to that under RIL (Peña-Claros et al. 2008; Villegas et al. 2009) |
| Carbon emission reductions and | More than 100 Mgha$^{-1}$ (Putz et al 2008) | Reduced by at least 30% ( Putz et al 2008) | |
| International agreements | None | Possibly used under the REDD+ agreements | Possibly used under the REDD agreements |

## Carbon Stock Calculation

Mean annual increments reported by Wadsworth and Zweede (Wadsworth & Zweede 2006) in $m^3$ $ha^{-1}$ $yr^{-1}$ (SV) were converted into total tree carbon stocks in MgC (CS) using Brown's (Brown 1997) equation:

CS = CT * WD * SV * BEF

where CT is carbon content, CT=0.5; WD is wood density, WD=0.57; BEF is the biomass expansion factor of 1.74
SV=0.56 $m^3$ $ha^{-1}$ $yr^{-1}$ for RIL, and SV=0.67 $m^3$ $ha^{-1}$ $yr^{-1}$ for RIL+ (Wadsworth & Zweede 2006).

Table SM2 Legal lower tree-size limits (breast-height diameter) for some commercial tree species harvested from tropical forests

| Common Name | Scientific Name | Family | Diameter Limit (cm) |
|---|---|---|---|
| Cambodia (Kim Phat 1997) | | | |
| Khwaav | *Adina cordifolia* | Rubiaceae | 45 |
| Beng | *Afzelia xylocarpa* | Leguminosae | 45 |
| Phkay Prik | *Afzelie bijuga* | Leguminosae | 45 |
| Bang kao | *Aglaia gigantia* | Meliaceae | 35 |
| Chreis | *Albizzia lebbek* | Mimosaceae | 45 |
| Kraay Sa | *Albizzia thorelli* | Mimosaceae | 30 |
| Phdeak | *Anisoptera glabra* | Dipterocarpaceae | 45 |
| Chan Krisnaa | *Aquilaria crasna* | Thymeleaceae | 35 |
| Khnol Prey | *Artocarpus altilus* | Moraceae | 45 |
| Sam Por | *Artocarpus sampor* | Moraceae | 35 |
| Pha Ong | *Callophyllum calaba* | Guttiferae | 30 |
| Khtiing | *Calophyllum dryobalanoides* | Guttiferae | 30 |
| Tra Maeng | *Carallia lucida* | Rhizophoraceae | 45 |
| Haisaan/Chansor | *Cassia garretiana* | Leguminosae | 45 |
| Ang kanh | *Cassia siamealpinées* | Leguminosae | 45 |
| Same | *Ceriops roxburghiana* | Rhizophoraceae | 45 |
| Woi young | *Chukrasia tabularis* | Meliaceae | 60 |
| Cheik Tum | *Cinnamonmum litsaefolium* | Lauraceae | 30 |
| Lo Ngeang | *Cratoxylon prunifolium* | Guttiferae | 30 |
| Sdey | *Crudia chrysantha* | Leguminosae | 30 |
| Trabb Tum | *Crypteronia paniculata* | Crypteroniaceae | 30 |
| Srol Krahorm | *Dacrydium elatum* | Podocarpaceae | 45 |
| Neang Nuon | *Dalbergia bariensis* | Leguminosae | 45 |
| Kra Nhuung | *Dalbergia cochinchinensis* | Leguminosae | 45 |
| Cheung Chaab | *Dasymachalon lamentaceum* | Annonaceae | 45 |
| Kra Lanh | *Dialium cochinchinensis* | Leguminosae | 45 |
| Angkot Khmao | *Diospyros bejaudi* | Ebenaceae | 45 |
| Traying | *Diospyros helferi* | Ebenaceae | 45 |
| Chheu Khmao | *Diosyros sp* | Ebenaceae | 45 |
| Chheu Tiel Bang | *Dipterocaprpus costatus* | Dipterocarpaceae | 60 |
| Chheutiel Tik | *Dipterocaprpus alatus* | Dipterocarpaceae | 60 |
| Kuoy/Neang deang | *Dipterocaprpus dyeri* | Dipterocarpaceae | 60 |
| Traach | *Dipterocaprpus intricatus* | Dipterocarpaceae | 50 |
| Chheutiel Thngor | *Dipterocaprpus jourdainii* | Dipterocarpaceae | 60 |
| Tbaeng | *Dipterocaprpus obtusifolius* | Dipterocarpaceae | 45 |
| Khlong | *Dipterocaprpus tuberculatus* | Dipterocarpaceae | 50 |

| | | | |
|---|---|---|---|
| Hundaang | *Disoxylon loureiri* | Meliaceae | 45 |
| Priing | *Eugenia sp.* | Myrtaceae | 30 |
| Taa Traav | *Fagraea fragrans* | Loganiaceae | 45 |
| Tra Muung | *Garcinia schomburghiana* | Guttiferae | 45 |
| Pruus | *Gercinia ferrea* | Guttiferae | 30 |
| Atit | *Hassia cuneata* | Lauraceae | 45 |
| Aataing/ Rotaing | *Homalium annamensis* | Flacourtiaceae | 35 |
| Koki Thmor | *Hopea ferrea* | Dipterocarpaceae | 50 |
| Koki dack | *Hopea helfera* | Dipterocarpaceae | 50 |
| Koki masao | *Hopea odorata* | Dipterocarpaceae | 50 |
| Koki khsach | *Hopea pierre* | Dipterocarpaceae | 45 |
| Po Peil | *Hopea recopei* | Dipterocarpaceae | 50 |
| Kra Bao | *Hydnocarpus anthelmitica* | Flacourtiaceae | 30 |
| Kraa Sa | *Kayea engeniafolia* | Guttiferae | 30 |
| Smaa Krabey | *Knema coricisa* | Myristicaweae | 45 |
| Sralao/Enthaneil | *Lagerstroemia sp* | Lythraceae | 35 |
| Bei Leuy | *Litsea veng* | Lauraceae | 45 |
| Sway Prey | *Mangifera indica* | Anacardiaceae | 45 |
| Kaes | *Manikora alexandra* | Sapotaceae | 45 |
| Smach | *Melaleuca leucadendron* | Myrtaceae | 30 |
| Kreul | *Melanorrhea laccifera* | Anacardiaceae | 45 |
| Bos Neak | *Mesua ferrea* | Guttiferae | 30 |
| ThLork | *Parinarium annamensis* | Rosaceae | 45 |
| Srakum | *Payena elliptica* | Sapotaceae | 45 |
| Triel | *Peltophorum dasyrachis* | Leguminosae | 35 |
| Traseik/ Tramkang | *Peltophorum ferrugineum* | Leguminosae | 35 |
| Raing Phnom | *Shorea siamensis* | Dipterocarpaceae | 45 |
| Sral | *Pinus merkusii* | Pinasae | 45 |
| Srol Sor | *Podocarpus cupnessina* | Podocarpaceae | 45 |
| Thnong | *Pterocarpus pedatus* | Leguminosae | 45 |
| Kampiing Reach | *Sandoricum indicum* | Meliaceae | 45 |
| Kdol | *Sarcocephalus cordatus* | Rubiaceae | 30 |
| Koki Phnorng | *Shorea hypochra* | Dipterocarpaceae | 45 |
| Phchek | *Shorea obtuse* | Dipterocarpaceae | 45 |
| Lum boi | *Shorea sp.* | Dipterocarpaceae | 45 |
| Khchov | *Shorea thorelli* | Dipterocarpaceae | 45 |
| Char Chong | *Shorea vulgaris* | Dipterocarpaceae | 60 |
| Kra Koh | *Sindora cochinchinensis* | Leguminosae | 45 |
| Chan Tumpaing | *Sterculia campanulata* | Sterculiaceae | 45 |
| Angkat Tmaat | *Stereospermum cheloneoldes* | Bignoniaceae | 45 |
| Sway Chamreang | *Swintonia pierri* | Anacardiaceae | 45 |
| Dounchaem Spong | *Tarrietia javanica* | Sterculiaceae | 45 |

| | | | |
|---|---|---|---|
| Mai Sak | *Tectona grandis* | Verbenaceae | 45 |
| Ta Uor | *Termanlia chebula* | Combretaceae | 45 |
| Praa Dam Leng | *Terminalia mucronata* | Combretaceae | 40 |
| Chhliik | *Terminalia tomentosa* | Combretaceae | 45 |
| Sam Pung | *Tetramels nudiflora* | Datiscaceae | 60 |
| Chhamm Chhaa | *Toona febrifuga* | Meliaceae | 30 |
| Chramas | *Vatica astrotricha* | Dipterocarpaceae | 30 |
| Tra Lat | *Vatica philastreana* | Dipterocarpaceae | 30 |
| Popuul or Phneis | *Vitex sp.* | Verbenaceae | 45 |
| Sokrom | *Xylia dolabriformis* | Leguminosae | 45 |

Some commercial species from Amazonian Brazil (Wellhöfer 2002)

| | | | |
|---|---|---|---|
| Sucupira vermelha | *Andira unifolialata* | Fabaceae | 60 |
| Amapá | *Brosimum parinarioides* | Moraceae | 55 |
| Guariuba | *Clarisia racemosa* | Moraceae | 50 |
| Angelim vermelho | *Dinizia excelsa* | Mimosaceae | 50 |
| Sucupira preta | *Diplotropis triloba* | Fabaceae | 50 |
| Cumarú | *Dipteryx odorata* | Fabaceae | 50 |
| Jatobá | *Hymenaea courbaril* | Caesalpiniaceae | 50 |
| Angelim pedra | *Hymenolobium heterocarpum* | Fabaceae | 60 |
| | *Hymenolobium nitidum;* | Fabaceae | 60 |
| Massaranduba | *Manilkara huberi* | Sapotaceae | 60 |
| | *Mezilaurus duckei* | Lauraceae | 50 |
| Louro itaúba | *Mezilaurus sinandra* | Lauraceae | 50 |
| Louro gamela | *Nectandra (Ocotea) rubra* | Lauraceae | 50 |
| Louro preto | *Ocotea fragantissima* | Lauraceae | 60 |
| Uchi torrado | *Sacoglottis guianensis* | Humiriaceae | 60 |
| | *Vantanea parviflora* | Humiriaceae | 60 |

Some commercial species in Bolivian forest

| | | | |
|---|---|---|---|
| Blanquillo | *Ampelocera ruizii* | Ulmaceae | 50 |
| Peroba-poca | *Aspidosperma cylindrocarpon* | Apocynaceae | 50 |
| | *Caesalpinia pluviosa* | Caesalpiniaceae | 50 |
| Cachimbo | *Cariniana domestica* | Lecythidaceae | 50 |
| Jequitiba | *Cariniana estrellensis* | Lecythidaceae | 50 |
| | *Cariniana ianeirensis* | Lecythidaceae | 50 |
| Cedro | *Cedrela fissilis* | Meliaceae | 50 |
| Fromager | *Ceiba pentandra* | Bombacaceae | 50 |
| Ararib | *Centrolobium microchaete* | Fabaceae | 50 |
| Guariuba | *Clarisia racemosa* | Moraceae | 50 |

| | | | |
|---|---|---|---|
| Capa | *Cordia alliodora* | Boraginaceae | 50 |
| Bibosi colorado | *Ficus boliviana* | Moraceae | 70 |
| Ajo-ajo | *Gallesia integrifolia* | Phytolaccaceae | 50 |
| Catahua | *Hura crepitans* | Euphorbiaceae | 70 |
| Jatobá | *Hymenaea courbaril* | Caesalpiniaceae | 50 |
| Iba | *Pouteria nemorosa* | Sapotaceae | 50 |
| Nui | *Pseudolmedia laevis* | Moraceae | 50 |
| Amendoim | *Pterogyne nitens* | Caesalpiniaceae | 50 |
| Pinho Cuiabano | *Schizolobium amazonicum* | Caesalpiniaceae | 50 |
| Mombin | *Spondias mombin* | Anacardiaceae | 50 |
| Sucupira | *Sweetia fruticosa* | Fabaceae | 50 |
| Caoba, Mogno | *Swietenia macrophylla* | Meliaceae | 70 |
| Tahuari | *Tabebuia serratifolia* | Bignoniaceae | 50 |
| Sura | *Terminalia oblonga* | Combretaceae | 50 |

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