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Impact of selective logging on the carbon stocks of tropical forests: Republic of Congo as a case study

Deliverable 6: Logging impacts on carbon stocks

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Executive Summary

The harvesting of timber from forests is a central part of the economy of tropical nations as is exemplified by the case of the Republic of Congo. Land use change in the tropics contributes up to 25 % of current international CO_2 emissions. Monitoring of logging activities therefore serves an important function. This report develops and presents methods for evaluating the carbon impact of selective logging in the tropics, with the purpose of facilitating the monitoring of forest management and improving understanding of the global carbon cycle.

The aim of the study was to derive factors to link reported data and aerial imagery with carbon impact. Our study site was the 2004 logging sites of Congolaise Industrielle du Bois (CIB), a Swiss-German timber company in the north of the Republic of Congo. During the course of the study a methodology was developed that can be applied to other areas and regions practicing selective logging. The size of the gap, and the dimensions of the felled tree and the commercial log, was determined in 99 logging gaps in the Republic of Congo, plus we recorded data on all trees severely damaged or killed as a result of the treefall. In addition we calculated the carbon impact of both skid trails and logging roads.

The mean diameter of extracted trees was 123 cm and length was 22 m. This compares with 70 cm and 11 m in a similar study in Bolivia. The mean extracted volume per logging gap was 25.1 m^3.

Winrock collected three-dimensional aerial digital imagery over 1,194 ha of the 2004 CIB logging concessions. This approximates 10 % of the total 2004 logging area. Employing the derived scaling factors we estimate that, across the concession, 11 m^3 are extracted per ha, or the equivalent of 0.53 trees/ha. The data reveals the total biomass carbon affected by logging practices in the CIB concessions in the Republic of Congo is equal to 10.20 t C/ha of concession or 37.40 t CO_2 e/ha.

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INTRODUCTION

Commercial logging of native forests is integral to the economies, and central to the development, of many tropical nations (FAO 2003). Internationally there is interest in improved forest management, in particular changes to reduced impact logging, motivated by biodiversity conservation, sustainable forest management, timber certification, and even the potential for increasing carbon stocks and obtaining carbon credits.

Monitoring changes in carbon stocks serves as a method of assessing the impact of forest management activities, and also helps determine the role forest harvesting plays in the global carbon cycle. Land-use changes in the tropics are a significant source of atmospheric CO_2, contributing up to about 25% of current fossil fuel CO_2 emissions (Prentice et al. 2001). Logging in the tropics tends to be selective, so the impact of harvest is hard to quantify and consequently current estimates of the effects of tropical forest management are likely to be inaccurate.

Monitoring of legal and illegal logging has several purposes. For example, assessments are needed of the integrity of conserved areas, such as National Parks, with regard to incursions by loggers, or, where a logging concession has been granted, there may be a need to assess whether that concession is being fulfilled within the contractual constraints. Alternatively, in the future it is envisioned that a premium will be paid for timber that is certified to come from a sustainably managed forest. To maintain the value of the certification, monitoring would have to be carried out.

In this study we concentrated on carbon stocks, which can be used as a proxy for other monitoring purposes. To monitor logging impacts on carbon stocks, factors are required to link reported data or readily monitored components with the total carbon impact. The two most obvious factors for correlation are volume extracted (which is widely reported) and gap size (which can be determined remotely). Correlation factors can be created through an initial set of ground measurements. To our knowledge only one study has created factors linking gap size or volume extracted with biomass damaged (Brown et al. 2000). Many studies have examined logging and associated damage both in conventional and reduced impact scenarios; however, these studies have largely focused on the number of trees damaged (e.g. Uhl and Vieira 1989, Uhl et al 1991, Verissimo et al. 1991, White 1994). The study of Pinard and Putz (1996) detailed the carbon impact, but not in the context of gap size or even volume of timber extracted.

This study focuses on the logging concessions of CIB (Congolaise Industrielle du Bois), located in the forests of the northern Republic of Congo in Central Africa.

In this study we aimed to estimate the net impact of selective logging on the forest carbon stocks by :

1) estimating on a gap-by-gap basis extracted volumes, the biomass carbon from the timber tree that remains in the forest, and the incidental carbon damage to surrounding vegetation; and
2) creating relationships between volume extracted, the size of canopy gap caused by logging and the carbon impact.

We then discuss how such data and relationships can be used to estimate the impact of logging on the total carbon budget, using such information as timber extraction rates or area and number of felling gaps from aerial imagery.

STUDY AREA

The study area was the 2004-harvest forest zones operated from the Ndoki 2 logging camp of Congolaise Industrielle des Bois (CIB), a Swiss-German timber company, in Sangha Province in the northern Republic of Congo (hereafter referred to as Congo)(Figure 1). The elevation of the area is approximately 450 meters above sea level, with gentle to flat topography. The mean annual rainfall is about 1300 mm with a mild dry season of 2-3 months. The forest concession contains trees as large as 3.5 m diameter at breast height, reaching heights in excess of 50 m. Trees, with a dbh of between 80 and 220 cm, of up to 20 timber species are felled.

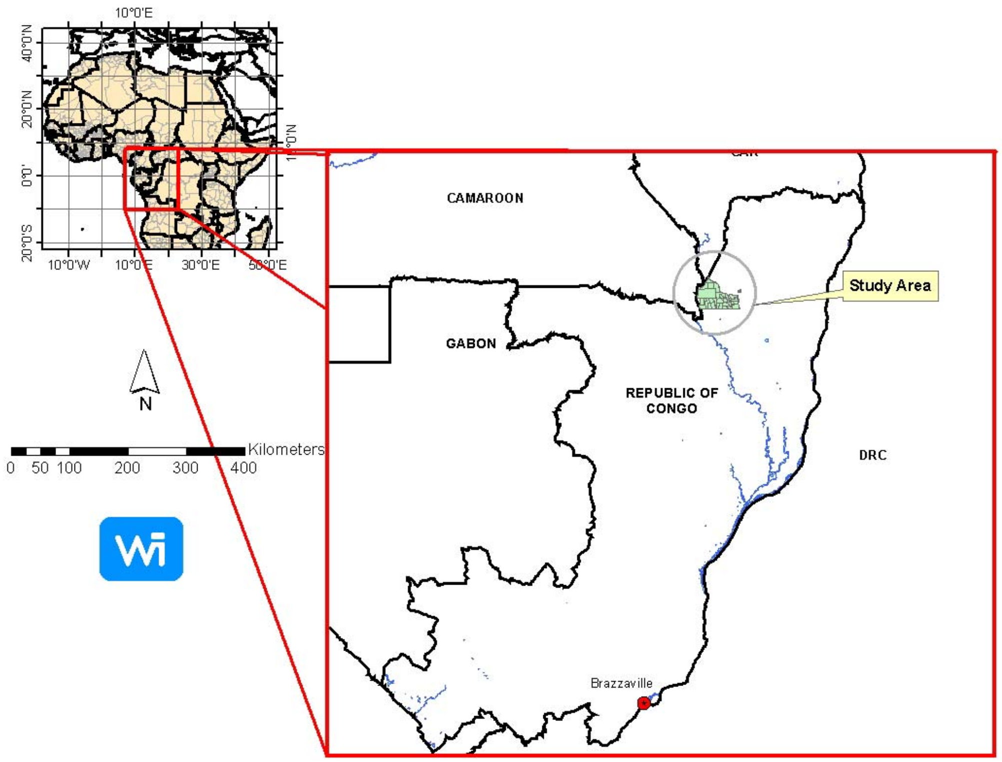


Figure 1. Location of the study area: CIB logging concessions in the Republic of Congo

In the region, logging operations are selective and the trees are felled with a chainsaw (Figure 2) and extracted from the forest by skid trails and roads. Once the timber tree is felled, the crews extract the portion of the tree that is commercially valuable. The skidder follows shortly after and extracts the cut section. The rest of the timber tree (branches, crown, stump) is left behind in the forest, along with other dead trees damaged during felling (Figure 3).

Figure 2. A cut timber tree

Figure 3. The branches left in the forest after timber extraction

METHODS

General Approach

The carbon impact of logging is calculated as the difference in carbon stocks between a forest that has been harvested and one that is not. Our method is to focus on the logging gaps. To estimate the change in live biomass, one could measure the live biomass in a concession before a block was logged and then again after it was logged; the difference would give the change in the live biomass C. However, the main problem with this approach is that two large C pools are being compared, and although the error on each pool could be small, the error on the difference, expressed as a percent, will be much larger. It is more appropriate to measure the change in live and dead biomass pools due to logging directly in the harvesting gaps. The change in live and dead biomass between the with- and without-logging cases is a result of the extraction of timber and damage to residual trees from the logging activities.

Estimating the carbon impact is more complex than just recording the change in live biomass. Ultimately, the entire timber tree and all trees incidentally damaged will be oxidized. However, in the immediate term carbon that progresses from live to dead wood is only emitted once decomposition has occurred, and the portion of the timber tree that is converted to long term wood products will not be emitted for the life time of the products (Figure 4).

The difference in carbon stocks between with- and without-logging scenarios equals:

(biomass carbon removed during logging + biomass carbon damaged/dead as a result of logging)
– (damaged/dead biomass carbon –decomposition of damaged/dead biomass)
– (wood products biomass carbon – wood products decomposition)

[1]

An additional term could be added if it was found that there was a growth differential between the logged area and adjacent unlogged areas (the term would consist of adding or subtracting the growth differential per year for the given area of logging gaps for the given number of years of growth difference). We also assume that selective logging has no impact on soil carbon over a large concession because of the small area impacted.

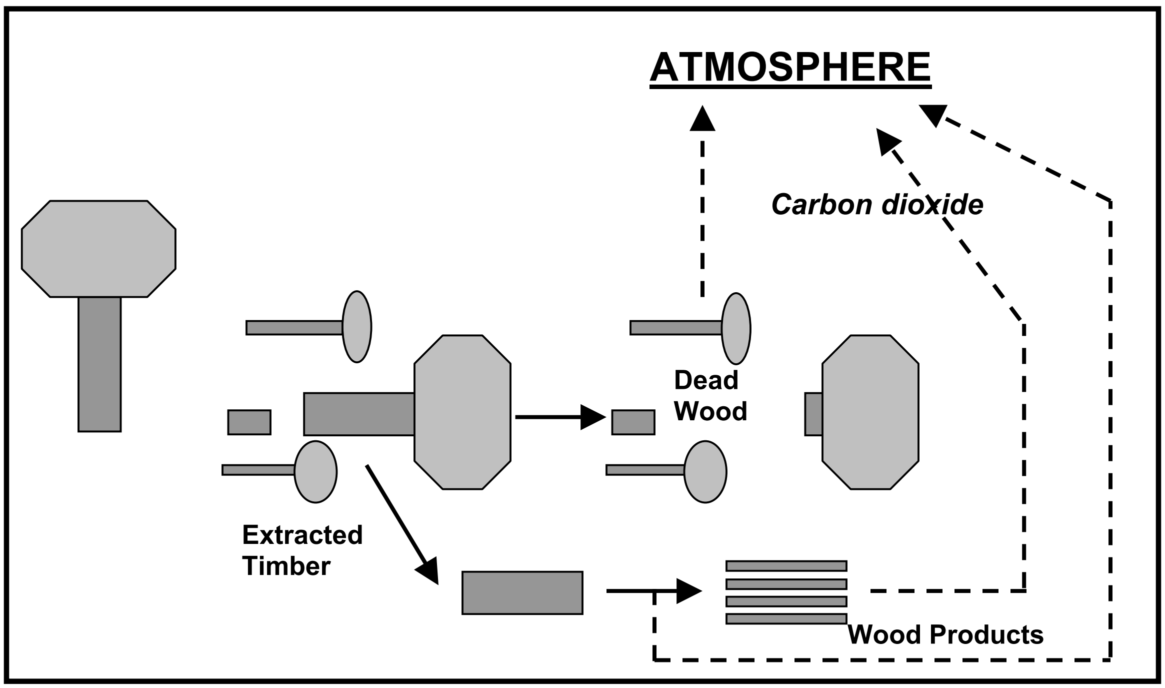


Figure 4. Schematic representation of carbon flow as a result of selective harvest in the tropics

In this study we focused on the carbon impact of felling and extracting the timber. We did not trace the processes of decomposition of dead wood or wood products, nor was the conversion efficiency of processing mills included. Instead we estimated factors to determine the volume and biomass carbon extracted from the forest and the biomass carbon remaining in the forest to decompose. We discuss the effect of including decomposition of the dead biomass and the proportion going into long term wood products on the net change in carbon stocks on the forest.

Figure 5. Extracted timber logs

Figure 6. Processed timber ready for export.

Field measurements

<u>Timber extraction</u>

A total of 99 selective logging gaps were examined in Congo in October 2004 (Figure 7).

Four measurements were taken on each timber tree: the diameters at both the stump and crown ends of each commercial log, the length of the commercial log and the diameter at breast height (dbh) of the tree. Measurements were made before the log was skidded out (cut marks for the commercial log had already been made by the logging crew).

Volume of the extracted log was calculated by multiplying length by the average of the cross-sectional areas at the foot and crown ends of each log. Biomass of the commercial log was calculated by multiplying the estimated volume by the wood density. A species-specific density was used when the species was identified or a mean tree density when the species was not known (0.58 Mg m^{-3}; Brown 1997). Here and throughout this study carbon is approximated as biomass x 0.5.

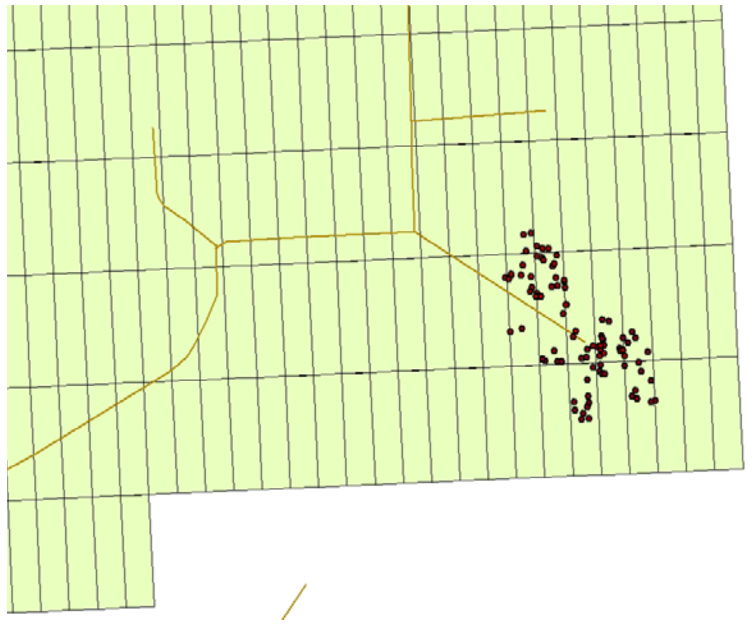


Figure 7. A section of the CIB logging concession. The 25 ha logging blocks (250 m x 1000 m) are illustrated. Logging roads are shown in orange. Sites of logging gaps where measurements were taken are illustrated by black dots.

We estimated the total (aboveground) biomass of the felled tree by applying a general moist tropical biomass regression equation (Biomass (kg) = $\exp\{-2.289+2.649*\ln(dbh)-0.021*(\ln(dbh)^2)\}$; r2 = 0.97; n = 172; range = 5-148 cm dbh) to the dbh. Finally the biomass of the tree crown and stump was estimated by subtracting the biomass of the extracted log from the total biomass of the felled tree.

The area of the logging gaps was estimated as the area with unimpeded direct vertical penetration of light. A best approximation was made of the shape of the gap, and the necessary dimensions to estimate the area were recorded.

Incidental-damage measurements

Damaged trees were those trees that were severely impacted by tree fall. Damage trees were classified as either 1) snapped stem or 2) uprooted. To estimate the amount of damaged vegetation in each plot, the general biomass equation (see above) was applied to measurements of dbh of the damaged trees. The minimum breast height diameter for measurement was 10 cm. During the felling of a large timber tree it is possible that large branches could be broken off from neighboring surviving trees. However, careful inspection in each plot to the best of our ability recorded such events in only one plot; in this case the biomass carbon of the branches was also estimated based on volume estimation and subsamples for wood density.

The total damage caused by logging was calculated as the sum of the biomass of the crown and stump of the felled tree, plus the biomass of snapped and uprooted trees.

Estimation Factors

To estimate carbon impact from readily available indicators, we created factors linking: 1) extracted volume with extracted biomass and damaged biomass left as dead wood in the forest and, 2) area of logging gaps and extracted volume, extracted biomass and damaged biomass left as dead wood in the forest.

Skid trails and Logging Roads

An additional carbon impact results from the construction of roads and skid trails for extracting timber from the forest (Figure 8,9,10).

In the field in Congo, we measured the dbh of all trees killed or severely damaged along ten skid trails (totaling 3.8 km). Using the general biomass equation of Brown (1997) we were then able to calculate the biomass carbon damaged per meter of skid trail for each of the ten trails.

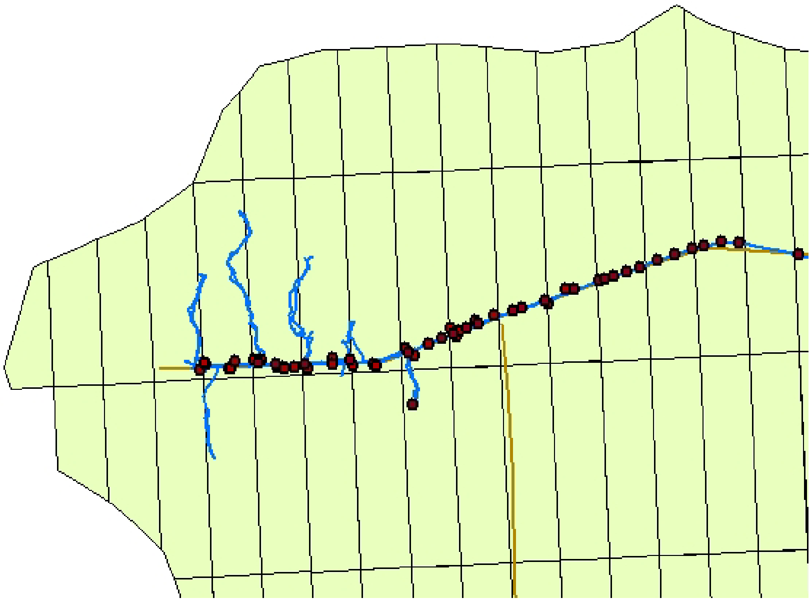


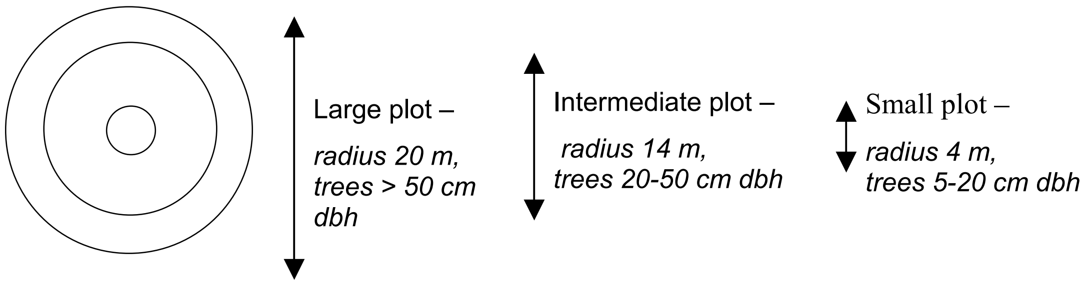
Figure 8. Part of the CIB logging concession showing 25 ha logging blocks and the location of six measured skid trails and the exit point to the logging road of all skid trails

Figure 9. Examples of skid trails in CIB concession

Roads are also used to transport the logs. We aimed to calculate the impact of logging roads through correlating area of roads (measured using imagery), with a measured stock for unlogged forest per unit area.

Figure 10. A logging road in the CIB concession in Congo

In Congo we estimated a mature forest stock by measuring 10 nested plots in forest that had not yet been logged within the CIB logging concessions. The schematic diagram below represents a three-nest circular sampling plot that we used in Congo for biomass determination.



Data and analyses at the plot level are extrapolated to the area of a full hectare to produce carbon stock estimates. Extrapolation by use of expansion factors occurs by calculating the proportion of a hectare that is occupied by a given plot. As an example, if a series of nested circles measuring 4 m, 14 m and 20 m in radius were used, their areas are equal to 50 m^2, 616 m^2 and 1,257 m^2 respectively. The expansion factors for converting the plot data to a hectare basis are 198.9 for the smallest, 16.2 for the intermediate and 8.0 for the largest nested circular plot.

RESULTS

Timber extracted

In the 99 logging impact plots in the CIB concession, 120 trees were harvested representing eight different timber species. Eighty of the logging impact plots consisted of a single harvested tree, and nineteen plots had more than one tree harvested in an area. Easily the most numerous species, among the felled trees, was *Entandrophragma cylindricum* (69.2 %) followed by *Entandrophragma angolense* (7.5 %).

Table 1. Components measured/estimated from the logging operations in the CIB concession. All values are mean ± 95 % confidence interval. (The volume per gap is higher than volume per tree because in 19 plots more than 1 tree was felled.)

	Mean	95 % CI
DBH (cm)	122.9	*±4.02*
Commercial log length (m)	22.2	*±0.81*
Volume / tree (m^3)	20.7	*±1.66*
Volume / gap (m^3)*	25.1	*±2.86*
Extracted biomass carbon (t C)	6.82	*±0.79*
Damaged biomass carbon (t C)	10.77	*±1.37*
Extracted timber as % of total tree biomass	50.3 %	*±2.1*

The mean size of the logging gaps was 719 m^2, with a range of 0 (closed canopy) to 2,769 m^2. The zero for the area of a logging gap in Congo represents one site where the treefall failed to do sufficient damage to the surrounding canopy to cause an opening. The mean dimensions of the logged timber trees were 123 cm dbh (range 84-211 cm), with a 22 m bole length (range 8.4-30.0 m), an extracted volume of 25.1 m^3 and an extracted biomass carbon of 6.82 Mg (Table 1).

Incidental damage

During measurements in 2004, 727 trees were recorded as severely damaged in the 99 logging impact plots. Of the damaged trees, 65 % had their stem snapped and 35 % were uprooted. Thirty-three percent of the damaged trees were measured in the minimum diameter class (10-19.9 cm).

Damage per Mg (1 Mg= 1 metric ton) extracted ranged from 0.63 to 10.39. Analysis of the logging impact plots with more than one harvested tree showed no significant difference from single stump plots (ANOVA; p>0.05). Mean amount of biomass carbon damaged per Mg C extracted was 1.5 for the multi-stem plots and 1.8 for single stump plots. The contribution of crown and stump biomass (i.e. portions of the tree not extracted at harvest) to total damage carbon biomass was high (66.0 % ± 3.6; mean ± 95 % confidence interval). On average, the amount of damage per Mg of timber extracted was 1.74 Mg.

Factors

In Congo, every cubic meter of timber extracted was equivalent to 0.27 Mg C extracted. In terms of damage, 0.46 Mg C were damaged and left to decompose in the forest for each cubic meter of commercial timber (Table 3, Figure 2). For every square meter of gap area 0.044 m^3 or 12.10 kg C were extracted, and 18.52 kg C were damaged and left to decompose in the forest (Table 2).

Table 2. Estimation factors for linking volume extracted and/or area of canopy gap with extracted volume and biomass carbon and damaged biomass carbon from logging operations in the CIB concession, Republic of Congo. One Mg = one metric ton

	Factor	95% CI
Mg C extracted / m^3 extracted	0.27	*±0.004*
Mg C damaged / m^3 extracted	0.46	*±0.05*
Mg C damaged / Mg C extracted	1.74	*±0.22*
m^3 extracted / m^2 of gap area	0.0444	*±0.0057*
Kg C extracted / m^2 of gap area	12.10	*±1.58*
Kg C damaged / m^2 of gap area	18.52	*±2.29*

Skid Trails and Logging Roads

Along ten skid trails (totaling 3.8 km), we determined a carbon impact equal to 6.83 kg C/m of skid trail ± 2.44 kg C/m (mean ± 95 % confidence interval).

From 10 plots in mature unlogged forest we estimated a carbon stock equal to 276.7 Mg C/ha ± 103.9 (n = 10, mean ± 95 % confidence interval). This is equal to 0.028 Mg C per m^2 of road area.

DISCUSSION

Comparison between selectively logged sites

Comparable results on the carbon impact of logging from other studies are very limited. The majority of studies tallied damaged stems rather than estimating biomass (e.g. Uhl and Vieira 1989, Uhl et al. 1991, Verissimo et al 1991, White 1994). In one other published study calculating damaged biomass, Pinard and Putz (1996) recorded 2.3 Mg damaged per Mg extracted from conventional logging in Sabah, Malaysia. In separate studies using identical methods, we estimated carbon damage of 3.1 Mg per Mg extracted in closed forest in Belize (unpublished data) and 2.78 Mg per Mg extracted in Bolivia (Pearson et al. 2005).

The damage values are highest in the studies in Central and South America, followed by Malaysia, and by Congo. One explanation may be the extracted proportion of the timber tree. In Bolivia, the mean bole length was only

10.8 m and the proportion of the total aboveground tree biomass that was extracted was just 40.1 %. In Belize, the mean bole length was just 9.8 m and the proportion extracted was 34.3 %. In Belize, therefore, there was a smaller proportion extracted and consequently a higher amount of damage per extraction. In Malaysia the timber trees were tall dipterocarps, consequently the bole lengths at Pinard and Putz's study site averaged 17.0 m (Tay 1996) and in the conventional logging areas the extracted proportion was 49 % of the preharvest biomass (Pinard and Putz 1996), resulting in lower mean damage per Mg extracted. Finally in Congo the mean bole length was 22 m and over 50 % is extracted leading to the lowest mean damage per extraction of all the sites (Figure 11).

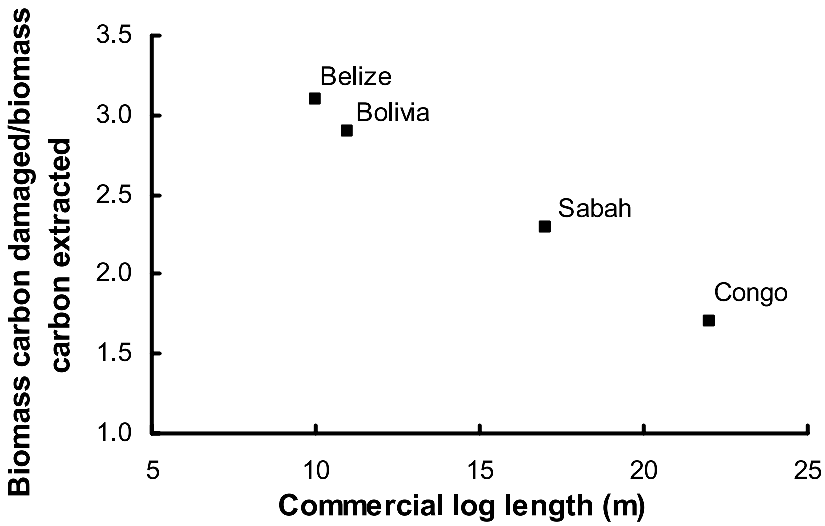


Figure 11. Relationships for four pantropical sites between commercial log length and the ratio between biomass carbon extracted and damaged

However, the damage to non-harvested tree biomass was also higher in Bolivia in relation to extracted biomass than in Congo. Two complimentary explanations for the difference in biomass damage between the sites may be the relative maturity of the forests and the presence or absence of lianas. In forests, such as those in Congo, where multiple trees per hectare are more than 1 meter in diameter, the density of non-commercial vegetation tends to be low. This low density results in a lower chance of the falling tree impacting surrounding trees and causing incidental damage. In fact, in Bolivia in each logging gap there were an average of 10.4 trees incidentally severely damaged, in Congo the average number of trees was 7.3. The presence of lianas may also be a cause of additional damage as liana connections cause additional treefalls simultaneous to the timber tree. Lianas were present in the forest in Bolivia but were not encountered in Congo.

Scaling factors

Estimation factors are presented that link volume extracted to biomass carbon extracted and biomass carbon damaged (Table 2). Volume extracted is a standard reported measure for forestry operations around the world. A potential problem could exist, however, with relying on reported volumes as: not all trees cut are extracted (up to 7 % of felled trees were not extracted in the Eastern Amazon; Holmes et al. 1999); records of extraction in some cases may be poor; and illegal extractions cannot be monitored. As an alternative, estimation factors are also detailed (Table 2) relating area of damage to extraction and carbon damage. These factors could be used in combination with aerial imagery to create a record not subject to the same doubts (aerial imagery has been collected in CIB concession and is in process of being interpreted).

For skid trails we estimated a mean carbon damage of 6.83 kg C per meter of skid trail. This impact is low because skid trails are narrow and skidders detour around large trees. The impact is lowered even further when it is considered that multiple extracted logs will likely use a single skid trail. If the trails measured represent a reasonable average for logging in the CIB concession, meaning skid trail length is 380 m, and if each skid trail is used by an estimated six trees, this represents an additional carbon impact equal to 2.6 Mg C / skid trail or 0.43 Mg C per harvested timber tree. We are aware of no comparable study.

For a given area of logged forest, with its associated number and area of roads, we would argue that the carbon impact of the roads is also low. In Congo the ‘feeder’ logging roads are 25 m wide (FAO 1997); so that a 400 m of road would be formed by clearing one hectare of forest. In Bolivia the same road-type is just 4 m wide (J. Torrico, CINMA forestry concession, Bolivia, personal communication), so that a 2500 m road would be formed by clearing 1 ha of forest. The impact of road building is reduced if it is considered that merchantable trees in the path of the road would be harvested rather than being left to decompose. CIB in Congo, on average, cuts and extracts between 1 and 2.5 (maximum) trees per hectare (Olivier Desmet, CIB, personal communication), which is equivalent to between 5.6 and 14.1 t C/ha of extracted timber. We estimate therefore that a 400 m road would lead to a carbon impact of 276 Mg C minus up to 14.1 Mg C or a net impact of 262 Mg C.

Impact of logging on the carbon budget

Equation 1 represents the total impact of logging on the forest carbon budget. In this study we have developed methods for determining the biomass carbon extracted and the biomass carbon damaged/dead as a result of logging. Additional components in the budget include any growth differential that arises between the logged and unlogged areas of forest, delayed mortality of damaged trees, and finally the consideration of the decomposition/oxidation of damaged biomass and the long term products arising from the extracted biomass.

Missing from our analysis is a determination of any differential in growth between logged and unlogged areas. Either the increased light in gaps could lead to increased growth relative to the surrounding forest, or the removal of the large timber tree or trees, which would previously have dominated biomass accumulation, could lower the mean rate of accumulation relative to uncut areas. In a study in Bolivia we looked at this issue (Brown et al. 2003) by measuring surviving trees in a zone incorporating the logging gap and a 5 m area around the gap, and pairing these measurements with measurements in adjacent unlogged plots. Measurements were taken immediately after harvest and again four years later. The rate of biomass accumulation was depressed in the logged plots. In the four years after harvest, the unlogged plots were accumulating carbon at a rate of 2.5 Mg ha^{-1} yr^{-1} as opposed to 1.3 Mg ha^{-1} yr^{-1} in the harvested plots. Over the 21.3 ha of logging gaps measured from the air in Bolivia (see above) this would create a carbon impact of 27.7 Mg. It remains unclear whether this effect can be extrapolated to other sites, such as we measured in Congo, nor do we know whether the effect will continue or even will be reversed beyond this four-year period. To our knowledge no one has carried out a comparable study.

Also missing from this analysis is a verification of the mortality of the severely damaged trees or an indication of the mortality of trees with minor damage. It could be expected that a proportion of snapped and uprooted trees would resprout. Pinard and Putz (1996) found that 82 % of trees that were snapped had resprouted 8-12 months after logging. Our own plots in Bolivia were revisited four years after logging (Brown et al. 2003), and we found that 64 % of snapped trees and 12 % of uprooted trees had resprouted. However, we would argue that, in terms of carbon, whether or not a tree resprouts is immaterial as the biomass present aboveground in the tree still enters the dead wood pool. A more serious missing factor may be lack of mortality data on minorly damaged trees. In Bolivia, 283 trees or an additional 28 % were impacted in a minor way, 80 (28 %) of these trees had died by the time of remeasurement four years later but the carbon impact is low because all had a dbh of less than 50 cm and 79 % had a dbh of less than 20 cm.

For conservation purposes, for the monitoring of concessions, and for forest certification, the destination of the dead wood and the extracted timber is less important. It matters, however, for carbon analyses. The immediate impact of logging to the atmosphere is diminished when it is considered that neither the dead wood pool in the forest, nor the extracted timber, in the form of the long-term product pool, are instantaneously oxidized. Instead, a proportion is oxidized each year forming a diminishing additional atmospheric input. It is not practical to track the decomposition of dead wood or wood products. Instead, decomposition/oxidation is modeled as a simple exponential function based on mass of dead wood/wood products and a decomposition coefficient (proportion decomposed per year).

The decomposition coefficient for dead wood is assumed to range from 0.05 – 0.12/yr based on literature sources for the tropics (Brown 1997, Delaney et al. 1998). As an example of the relevant calculations, we assume an extraction of 100 m^3 of timber per year. Using the damage factors given above, this results in a total of reduction of live biomass of 74.0 Mg C, of which 47.0 Mg C enters the dead wood pool. Assuming an efficiency of 40% for the conversion of logs to long-term wood products (Winjum et al. 1998), this results in 11 Mg C/yr entering the long-term product pool. Combining all the changes according to equation 1 above, the net impact of harvesting

100 m^3 of timber after one year is a net emission of 18.7 and 20.5 Mg C, for a decomposition rate of 5% and 10% respectively. Through time the dead wood pool increases and eventually levels off with the net change in this pool decreasing through time. After 30 years of continuous extraction of 100 m^3/yr, total timber extracted would be 3,000 m^3, live biomass would be reduced by 2,219 Mg C, damaged biomass would be 1,409 Mg C, the dead wood pool would have emitted 661 Mg C (using the conservative 5% decomposition rate in the typical exponential model of decompostion), the amount of carbon transferred to the wood product pool would be 324 Mg C, and the net emissions would be 1,147 Mg C. In other words, over a 30 year logging cycle, 0.38 Mg C would be emitted per cubic meter of timber harvested. Thus if a decision were made to stop logging and protect the forests instead, the net carbon benefit would be 0.38 Mg C per cubic meter of timber not harvested.

Incorporation of Aerial Data

In December 2004, Winrock International collected aerial imagery over 2004 logging areas. After data collection, analysis was conducted to determine the area of gaps and roads and the length of skid trails captured in the imagery. In Figure 12 a logging gap is shown at a high resolution. In Figure 13, the same strip of forest is shown twice, in B the gaps, roads and skid trails are delineated.

Figure 12. A logging gap recorded in the digital imagery

Figure 13. Strips of aerial imagery showing logging damage, in B the areas of damage are delineated. The imagery is designed to be seen in three dimensions and so some of the polygons are offset when seen in two dimensions

In our analysis of the imagery (full report to follow), 1,194 ha of the 2004 logging concession have been examined, or 10% of the area delineated for logging. From the analysis we calculated an extraction of 13,109 m^3 ± 813 (mean ± 95 % confidence interval), which is equal to 11.0 m^3 per hectare of concession ± 0.68 (mean ± 95 % confidence interval. In Table 3 the total carbon impact on this area and the carbon impact per hectare of concession is presented.

Table 3. The total carbon impact and the carbon impact per hectare as calculated from aerial imagery analyzed from 1,194 ha of forest in 2004 concession area

	Total carbon impact		**Impact per ha of concession**	
	t C		*t C/ha*	
Extracted biomass carbon	3,542	*± 232*	2.96	*± 0.19*
Damaged biomass carbon in logging gap	5,464	*± 321*	4.58	*± 0.27*
Damaged biomass carbon in skid trails	112	*± 9*	0.09	*± 0.007*
Biomass carbon impact of logging roads	3,056	*± 634*	2.56	*± 0.53*
TOTAL	12,174	*± 1,195*	10.20	*± 1.00*

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