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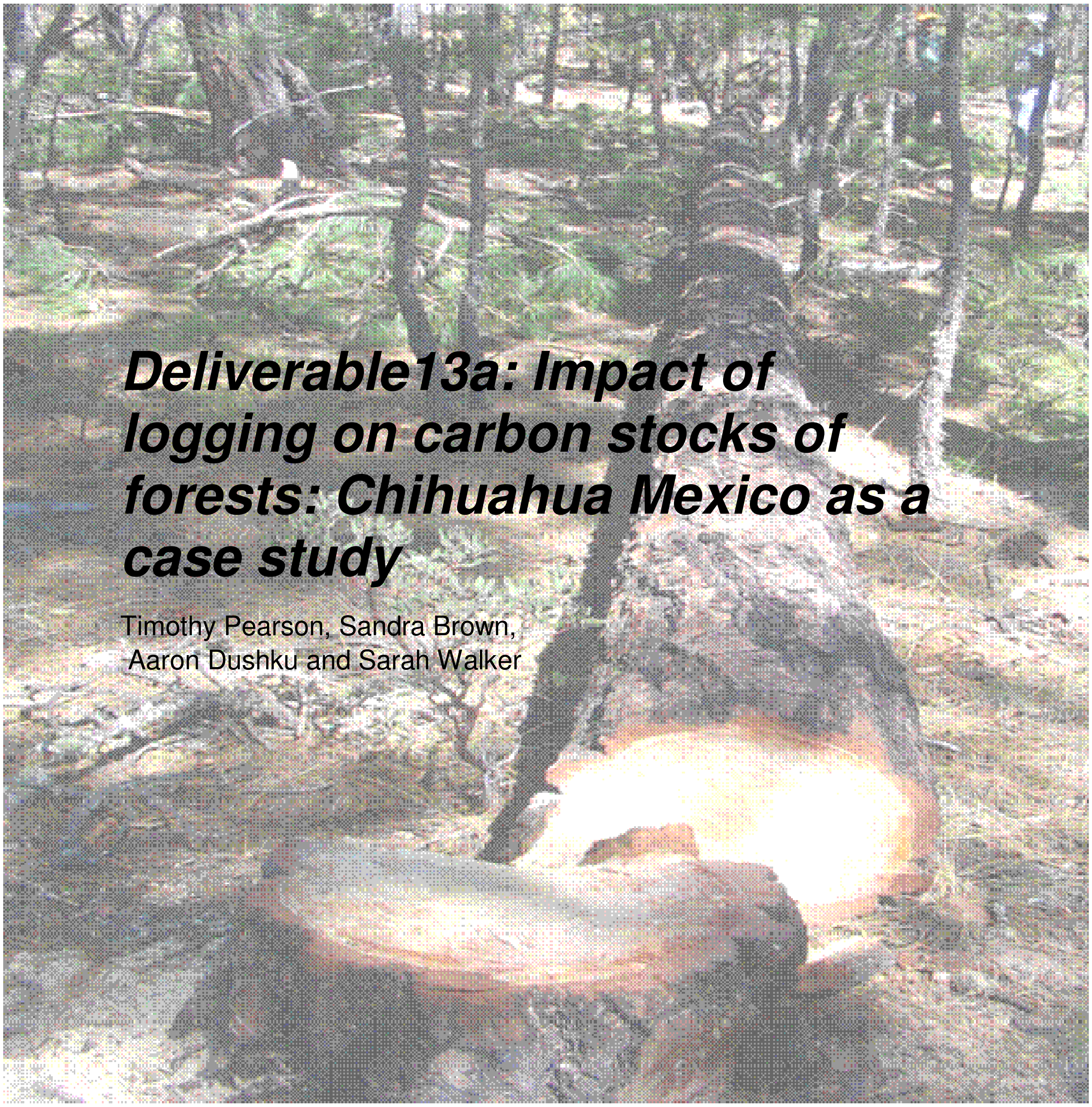

Deliverable13a: Impact of logging on carbon stocks of forests: Chihuahua Mexico as a case study

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WINROCK INTERNATIONAL

Putting Ideas to Work

Executive Summary

Commercial logging of native forests is integral to the economies, and central to the development, of many nations. 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 are a significant source of atmospheric CO_2, contributing up to about 25% of current fossil fuel CO_2 emissions. It is hard to quantify the impact of logging particularly selective logging, so current estimates of the effects of forest management are likely to be inaccurate.

In this study, the impact of logging on the carbon balance of the temperate pine forests in the Ejido of Chocachi, Chihuahua State in Mexico was assessed.

Seven trees were harvested to verify the relationship between biomass and diameter at breast height. One hundred and thirty-five felled trees were measured to correlate the relationship between extracted volume, and extracted carbon and carbon in dead wood after harvesting.

The forest in Chihuahua consisted of relatively short trees (< 20 m height) in an open low density pattern. The incidental damage was therefore low—for every ton of carbon extracted, 1.42 t C were damaged and left in the forest to decompose. The total biomass of dead wood relative to the length of the timber log was low compared to similar studies at tropical sites due to both the open forest structure and the very low minimum crown-end diameter for extraction.

The emissions avoided by stopping logging in the Ejido of Chocachi are detailed together with estimates off emissions avoided by decreasing the intensity of logging by 10 %. For the former case, the emissions avoided over a 10 year period would amount to about 24.5 thousand t CO_2 and for the reduction in harvesting by 10%, the emission avoidance over 10 year period would be 2.4 thousand t CO_2.

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INTRODUCTION

Commercial logging of native forests is integral to the economies, and central to the development, of many nations (FAO 2003). Internationally there is interest in improved forest management 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 are a significant source of atmospheric CO_2, contributing up to about 25% of current fossil fuel CO_2 emissions (Prentice et al. 2001). It is hard to quantify the impact of logging particularly selective logging, so current estimates of the effects of forest management are likely to be inaccurate.

In 2004, Winrock International visited a logging concession in the Republic of Congo, in Central Africa, and evaluated the impact of logging practices on carbon stocks (Brown et al. 2005). In this, the subsequent phase of the work Winrock visited a contrasting forest type – temperate pine forests in the mountains of Chihuahua State, Mexico in 2005.

As in the Republic of Congo, the focus was 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. In Mexico we concentrated on volume extracted rather than gap area because the pine forest is open and no felled tree is large enough to make a substantial impact on the prevailing canopy coverage. Before our work in Congo and Mexico, to our knowledge, only one study had 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 pine forests in the Chocachi ejido, located in Chihuahua State in Mexico (Figure 1). The principal aim was to estimate the net impact of selective logging on the forest carbon stocks by estimating extracted volumes, the biomass carbon from the timber tree that remains in the forest, and the incidental carbon damage to surrounding vegetation, and by creating relationships between volume extracted and the carbon impact.

The report is concluded with a discussion on how such data and relationships can be used to estimate the impact of logging and changes in logging practices on the total carbon budget.

Figure 1. The forest of Chocachi in Chihuahua, Mexico

STUDY AREA

The focus of our study was the ejido of Chocachi in Chihuahua State, Mexico (Figure 2). An ejido is a community that collectively holds and manages land. Chocachi has 5,397 ha of forestland that it manages for timber.

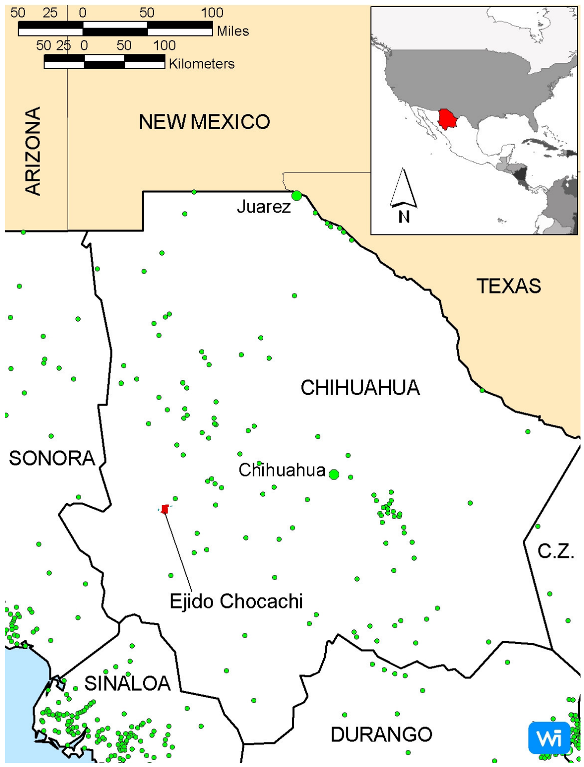

Figure 2. The study site Chocachi Ejido in Chihuahua, Mexico. The locations of major towns (green dots) across the region are illustrated

The high elevation pine forest of Chocachi is dominated by one species of pine, Arizona pine (*Pinus ponderosa* var. arizonica), with scattered individuals or small groups of oaks.

As a result of extensive harvest over more than 100 years, old growth pine-oak forest is considered by IUCN to be one of the most endangered habitat types in the world (Felger and Wilson 1994). The forests of Chocachi lie in the Sierra Madre Occidental. Historically the Sierra has played the roles of both a refuge during glacial periods, and a migration corridor between tropical and temperate biota. The consequence of this history is an immense diversity of plant and animal communities that has received relatively little recognition or protection (Felger et al. 1997).

The Ejido of Chocachi encompasses an area of 5,397 hectares at elevations between 2,177 and 2,711 meters above sea level.

LOGGING METHODOLOGY

The forest lands of Chocachi Ejido are split into annual harvesting units. Prior to the start of harvesting (March/April) each year, trees are marked to be cut. .

A total of approximately 8,600 cubic meters of pine trees are cut and extracted each year. The trees are divided among the community members and individual community members are responsible for harvesting their own trees.

Trees are felled by chainsaw (Figure 3). Branches are removed, chopped up and dispersed. The main stem is cut into sections (Figure 4) and skidded to roads (Figure 5) using a horse or donkey.

The logging unit is revisited every 15 years.

Aside from the timber trees the community members are permitted to thin the forest within the same unit. Oak and juniper trees are also cut and used for fuel wood.

Figure 3. A timber tree being felled in Chocachi

Figure 4. The process of cutting logs to extract from the forest

Figure 5. A pile of logs extracted from the forest in Chocachi

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 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 6).

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

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

[Eq. 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 assume that selective logging has no impact on soil carbon because of the small area impacted and thus soil is not incorporated into the model.

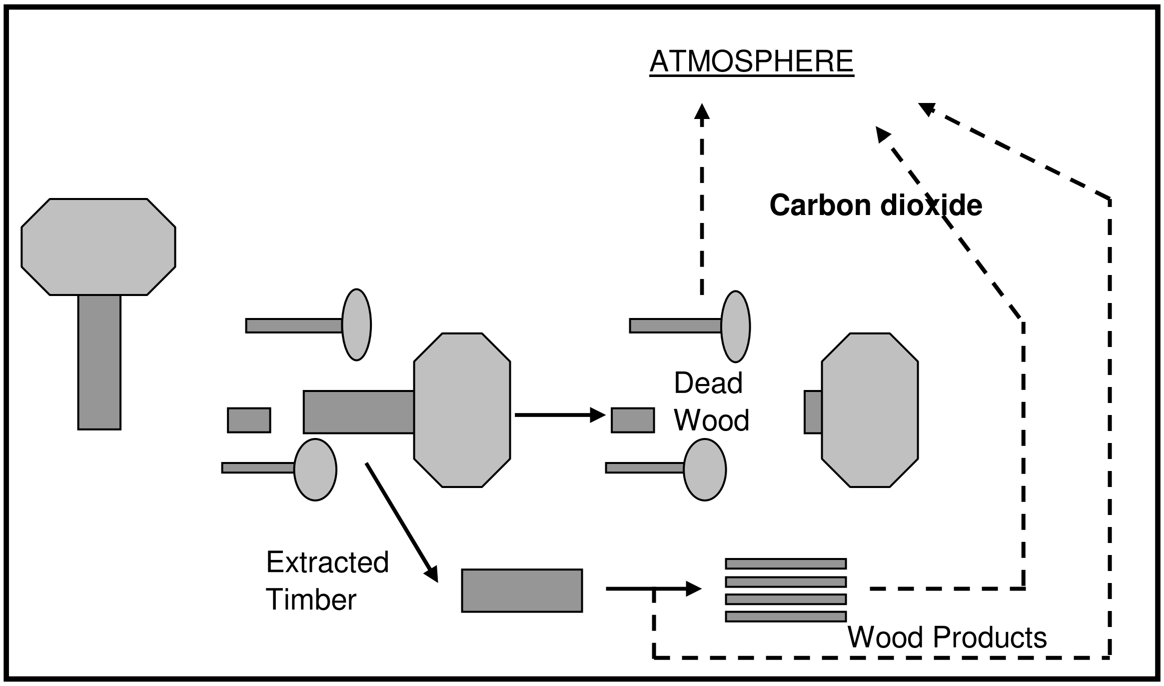

Figure 6. Schematic representation of carbon flow as a result of selective tree harvesting.

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.

Field measurements

The field measurements were carried out in May 2005 at the Chocachi Ejido in Mexico (Figure 7). The work was split into two components:

Harvesting trees – seven trees were harvested to ascertain the allometric relationships between biomass, height and DBH. From these data the most appropriate already existing equation can be chosen for estimating the biomass of the harvested trees.

Stumps – the stumps and crowns of 135 trees were measured to more broadly determine the relationship between volume extracted and biomass remaining as dead wood in the forest.

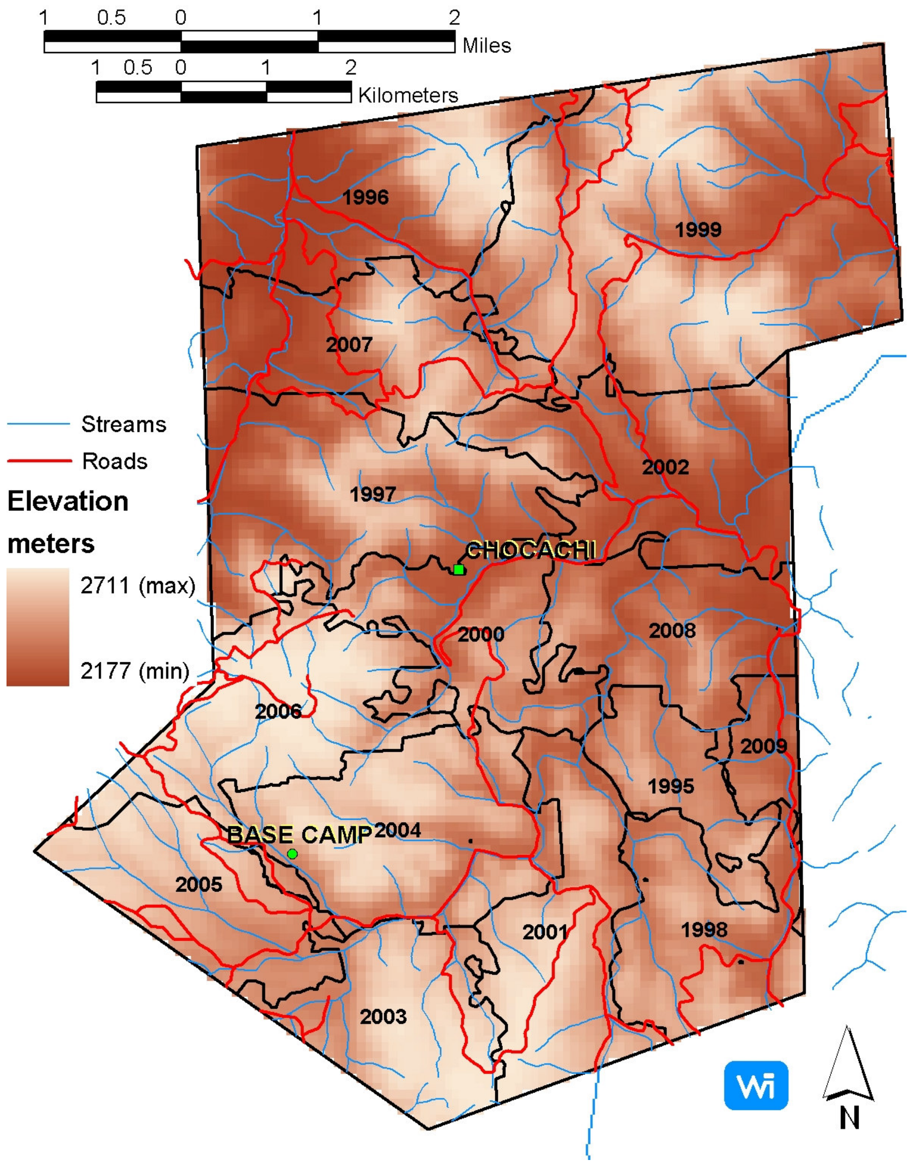

Figure 7. The Ejido of Chocachi showing roads, streams, logging units and the date of harvesting in the current cycle. The town of Chocachi and the location of the farm where the field team was based (base camp) are indicated.

<u>Harvested Trees</u>

Seven trees typical of those being harvest in the ejido, which were already scheduled for harvest, were felled using local practices. Once felled, all branches and all of the stem that would not be extracted were weighed (Figure 8). The dimensions of the timber log and of the stump were measured (Figure 9). Prior to felling, the DBH and height of the tree were measured. Subsamples of stem, branches and leaves were taken for determination of the ratio of wet to dry weight.

Figure 8. Weighing the branches and needles of a felled tree

Figure 9. Measuring the dimensions of the timber log of a felled tree

Measuring treefalls

A total of 135 felled trees were examined in Chihuahua in May 2005 (Figure 10).

Figure 10. Examining the site of a felled tree

In all cases the commercial log had already been removed (e.g. Figure 10) leaving the crown (Figure 11) and stump (Figure 12) of the tree. Four measurements were taken on each timber tree: the diameters at both the stump and crown ends of each commercial log, the distance between the stump and crown (length of timber log) and the height of the stump.

Figure 11. The crown of a felled tree

Figure 12. The stump of a felled tree

Volume of the extracted log was calculated by multiplying length (distance between the stump and the crown) by the average of the cross-sectional areas at the stump and crown ends of each log. Biomass of the commercial log was calculated by multiplying the estimated volume by the wood density. As the overwhelming majority of the trees were ponderosa pine (>94%), the species-specific density for this species was used. Here and throughout this study carbon is approximated as biomass x 0.5.

The biomass of the stump and crown of the tree were calculated by subtracting the biomass of the log from the total biomass of the tree. Total biomass of the tree was estimated using the allometric equation of Brown and Schroeder (1999) (see Results from felled trees). The DBH of the tree was calculated from the other measurements on the tree:

$$DBH = D_s - \left(\frac{D_s - D_c}{LL} * (130 - H_s) \right)$$

Where:	D_s	=	Diameter at stump (cm)
	D_c	=	Diameter at crown (cm)
	LL	=	Log length (cm)
	H_s	=	Height of stump (cm)

Any trees that were snapped or uprooted during the felling of the tree were noted and a DBH measurement was taken. For all pines, the equation of Brown and Schroeder was applied to estimate biomass. Where oaks or juniper were encountered the relevant equations of Jenkins et al. (2003) were applied.

RESULTS

Felled Trees

The results from the measurements on the seven felled timber trees are given below in Table 1.

Table 1. The dimensions and biomass of the trees felled as part of the study in Chocachi

Pinus Species	DBH (cm)	Height (m)	Log Length (m)	Log Volume (m^3)	Aboveground Tree Biomass (t biomass)
Arizonica	43.5	19.2	14.75	1.53	0.96
Arizonica	31.7	17.0	11.80	0.89	0.59
Arizonica	37.4	12.2	9.87	0.96	0.80
Durangensis	35.7	31.4	17.25	1.48	0.80
Arizonica	38.2	14.4	8.18	0.94	0.92
Arizonica	41.2	14.4	9.88	0.93	0.85
Arizonica	33.9	18.6	12.70	0.74	0.45

The DBH and aboveground biomass from the felled trees were then plotted along with the biomass predicted using three separate allometric equations (Figure 13):

- Jenkins et al. 2003: Pine Equation. Jenkins et al. (2003) created equations using pseudodata derived from 318 equations for over 100 species across the United States
- Brown and Schroeder 1999: Pine Equation. Brown and Schroeder created an equation from USFS Forest Inventory and Analysis permanent plot data in the Eastern United States.
- Belize: Pine Equation. Unpublished equation from 53 pine trees harvested in the savanna system in Belize.

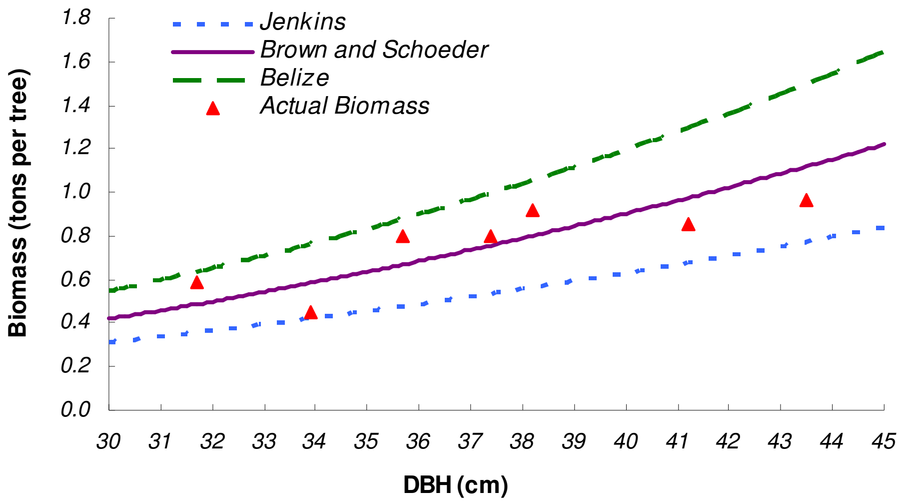

Figure 13. Relationship between DBH and tree biomass for seven tree harvested in Chocachi. Also plotted are the biomasses of trees predicted using three separate allometric equations

From Figure 13 it is clearly apparent that the data fits the equation of Brown and Schroeder (1999) best. This equation produced an r^2 value of 0.51 for the fit of the seven data points to the line. From this point forth the equation of Brown and Schroeder were used to extrapolate from DBH to biomass.

TIMBER EXTRACTED

Measurements were taken on 135 felled trees. Ninety-four percent of the measured trees were *Pinus ponderosa* var Arizonica. The mean DBH was 38 cm and mean log length 11.5 m resulting in a mean volume of 0.96 m^3 and extracted biomass of 0.18 t C (Table 2).

Table 2. Components measured/estimated from the logging operations in Chocachi. All values are mean ± 95 % confidence interval

	Mean	95 % CI
DBH (cm)	37.7	±1.39
Commercial log length (m)	11.5	±0.54
Commercial log volume (m^3)	0.96	±0.09
Extracted biomass carbon (t C)	0.18	±0.02
Damaged biomass carbon (t C)	0.25	±0.02
Extracted timber as % of total tree biomass	44 %	±0.02

Figure 14. A felled tree in Chihuahua Mexico

<u>Incidental damage</u>

Less than one tree was incidentally killed by each felled tree (0.69 trees incidentally killed per felled tree). The mean DBH of the incidentally killed trees was 9.6 cm with a range of 0.8 to 37.9 cm. The biomass of incidentally killed trees represents just 3 % of the total biomass left to decompose in the forest after logging. Therefore 97 % of the damaged biomass left to decompose is derived from the stump and the top of the felled tree.

Factors

In Chihuahua, Mexico, every cubic meter of timber extracted was equivalent to 0.38 tons C extracted. In terms of damage, 0.54 tons C of biomass were left as dead wood to decompose in the forest for each cubic meter of commercial timber.

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 tons damaged per ton extracted from conventional logging in Sabah, Malaysia. In separate studies, using identical methods, Winrock estimated carbon damage of 3.1 tons per ton extracted in closed forest in Belize (unpublished data), 1.74 tons per ton extracted in the Republic of Congo (Brown et al. 2005) and 2.78 tons per ton 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 ton 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.

However, Chihuahua clearly falls outside this pattern. The mean log length in Chihuahua is 11.5 m which would predict a damage ratio of approximately 3 tons per ton extracted. Instead in Chihuahua the ratio is 1.4 tons per ton (Figure 15).

A reason for the difference between Chihuahua and the tropical broadleaf forests could be in the minimum diameter acceptable in commercial logs. In Chihuahua the top end of the commercial log has a mean diameter of 19.0 cm (with a range of 7.8 to 49.1 cm); in contrast in the Congo the mean was 90.3 cm with a range of 56 to 150 cm. This low minimum diameter means that a much higher proportion of the total stem is extracted leaving a smaller proportion as dead biomass in the forest.

A second explanation in Chihuahua could be forest structure. The pine forests of Chihuahua are very open compared to broadleaf forests in the tropics or in temperate latitudes. An open forest combined with relatively short trees ensures that few trees are incidentally damaged during felling.

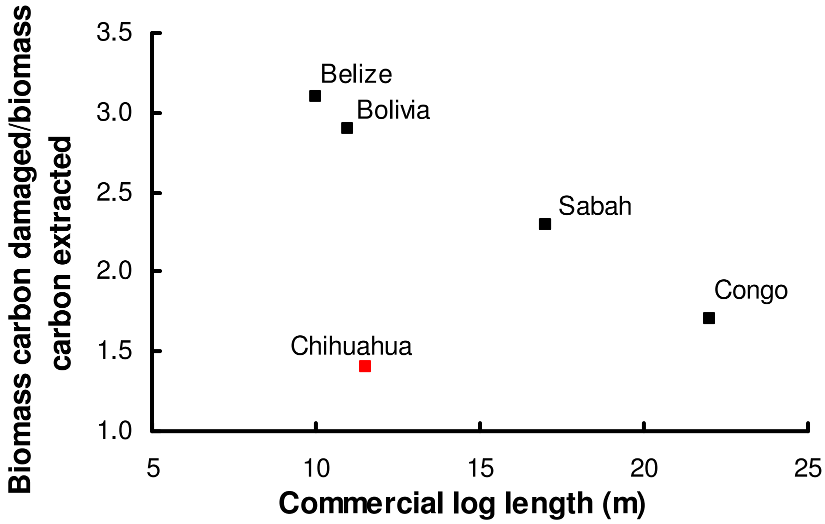

Figure 15. Relationships for four pantropical sites and Chihuahua, Mexico between commercial log length and the ratio between biomass carbon extracted and damaged

Scaling factors

Estimation factors are presented that link volume extracted to biomass carbon extracted and biomass carbon damaged. Volume extracted is a standard reported measure for forestry operations around the world. Here it is reported that 0.38 tons are extracted per m^3 and 0.54 tons are left in the forest as deadwood per m^3. 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. One solution to this problem is to create a relationship between carbon and the size of logging gaps. This, however, is not possible in Chihuahua because the open forest structure and small tree size make it impossible to identify the site of felled trees.

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, damage due to logging roads and skid trails 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 Chihuahua, where the canopy is open even in the absence of logging it is not expected that there will be a significant growth differential between logged and unlogged plots.

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. However, in Chihuahua, where less than one tree was damaged for each felled tree and where the mean DBH of damaged trees was just 9 cm, the survival of damaged trees will have little impact on the carbon budget.

Emissions from the creation of roads and skid trails are also not an issue for the forests of Chocachi. The roads are permanent roads that were created many years previously. The roads are typically narrow (< 3 m) so even the impact of the original creation would have been low compared for example to the Republic of Congo where roads (including loading decks) were often more than 15 m wide and the forest biomass through which the roads were carved were three times higher in the Congo. Skid trails in Chocachi were not apparent as the small logs were skidded out through the open forest structure using horses, mules or donkeys causing virtually no impact to the remaining vegetation.

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 and wood products and a decomposition coefficient (proportion decomposed per year). In the dry conditions of Chihuahua, the decomposition rate is very low and it is likely that the evolution of carbon dioxide is also low (see the following section).

Figure 16. Logs waiting for the truck to remove them to the local sawmill

MODELING A CHANGE IN HARVESTING PRACTICES

In Chocachi approximately 8,600 m^3 are cut every year. Of this total 5,250 m^3/yr are from commercial-timber trees. The remaining 3,350 m^3/yr is thinnings and fire wood. It is conservatively assumed here that none of these thinned trees form long-term wood products and that all logging slash is of a fine diameter and so is rapidly decomposed and oxidized. It is also assumed that the thinned trees, oaks and juniper trees are cut in all harvesting scenarios as the removal of these trees is required to retain a desirable forest structure.

A harvest of 5,250 m^3 / yr would be equivalent to 1,995 t C/yr extracted and 2,835 t C/yr left in the forest as dead wood (i.e. damage ratio of 1 t removed damages 1.42 tons).

Dead wood decomposition and retired wood products

Neither the extracted timber logs nor the dead wood remaining in the forest are immediately emitted to the atmosphere as carbon dioxide. A proportion of the extracted logs will be converted to wood products, which potentially remain in use for many years before being retired. Dead wood remains in the forest and decomposes through time. Through the process of decomposition, oxidation occurs with resultant emissions of CO_2. Here emissions from extracted timber are taken from extracted timber factors from the DOE 1605b technical guidelines (Appendix 4: Calculation methods for estimating carbon in wood products), and emissions from dead wood are estimated using the decomposition rate of Turner et al (2003). For both wood products and decomposition the factors for the Rocky Mountain region are taken as this region includes Arizona and New Mexico, which, in parts, closely approximate Chihuahua. For dead wood the decomposition factor for ponderosa pine is used. The emissions through time resulting from a single year's logging in Chihuahua are equal to 6,488 t CO_2e after 50 years or 8,744 t CO_2e after 100 years (Table 3).

Table 3. Estimated cumulative emissions resulting from a single year's harvest in Chocachi

	Cumulative Emissions (t C)			
Years	Dead Wood	Wood Products	TOTAL	t CO_2e
0	0	408	408	1,497
10	314	482	796	2,920
20	579	519	1,098	4,026
30	802	553	1,355	4,969
40	990	590	1,580	5,793
50	1,149	621	1,769	6,488
60	1,282	649	1,931	7,081
70	1,394	680	2,075	7,607
80	1,489	709	2,198	8,058
90	1,569	734	2,303	8,444
100	1,636	757	2,393	8,774

OPTIONS FOR CHANGE IN HARVESTING PRACTICES:

1. Stop logging

Stopping logging would reduce the timber cut and extracted by the full 5,250 m^3/yr. This would lead to avoided emissions equal to the totals in Table 3 (e.g. 2,920 t CO_2e [per year without logging] after 10 years, 6,488 t CO_2e after 50 years etc)

2. Reduce harvest by 10 %

Stopping logging entirely is generally not a realistic possibility. Instead the community may prefer to reduce the intensity of harvest. A reduction in the volume cut by 10 % would lead to an estimated removal of 4,725 m^3/yr that results in avoided emissions totaling 291 t CO_2e after 10 years and 647 t CO_2e after 50 years (Table 4).

Table 4. The emissions from a single year of conventional logging and of a 10 % reduction in logging intensity, plus the estimated avoided emissions

	Cumulative (t CO_2e)		
Years	Conventional	Reduced	Avoided Emissions
0	1,497	1,347	149
10	2,920	2,628	291
20	4,026	3,624	402
30	4,969	4,473	496
40	5,793	5,215	578
50	6,488	5,840	647
60	7,081	6,374	706
70	7,607	6,848	759
80	8,058	7,254	804
90	8,444	7,602	842
100	8,774	7,898	875

The form of the reduction in logging volume could be an increase in the minimum diameter for logging or not cutting the largest undamaged trees (termed as sobremaduros).

The carbon benefit given here is conservative because it does not include the additional growth that will occur in the 10 % that is not harvested.

Avoided emissions through time

Each year after the change in practice additional emissions will be avoided both from that year and from decomposition that would have occurred to dead wood and wood products from trees that were not harvested in previous years (due to the change in practice). This leads to avoided emissions totaling 24,454 t CO2e after 10 years and 59,873 t CO2e after 20 years for stopping logging completely or 2,441 t CO2e after 10 years, 5,975 t CO2e after 20 years for the 10 % reduction in intensity (Figure 17).

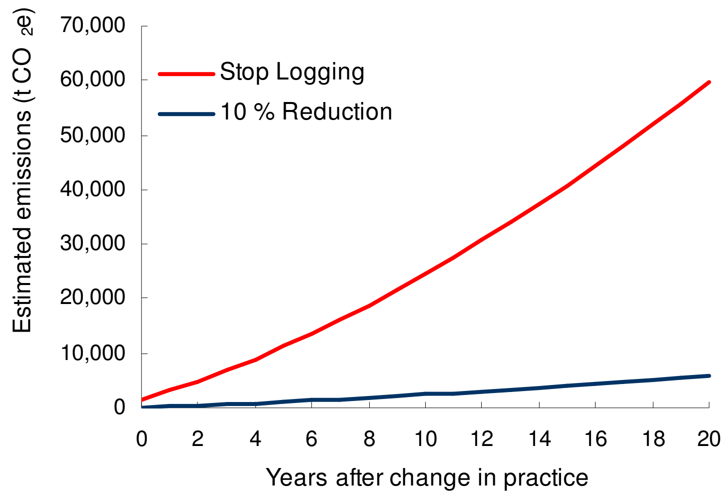

Figure 17. Illustration of the emissions avoided through time from two alternative changes in logging practice in the Chocachi Ejido

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