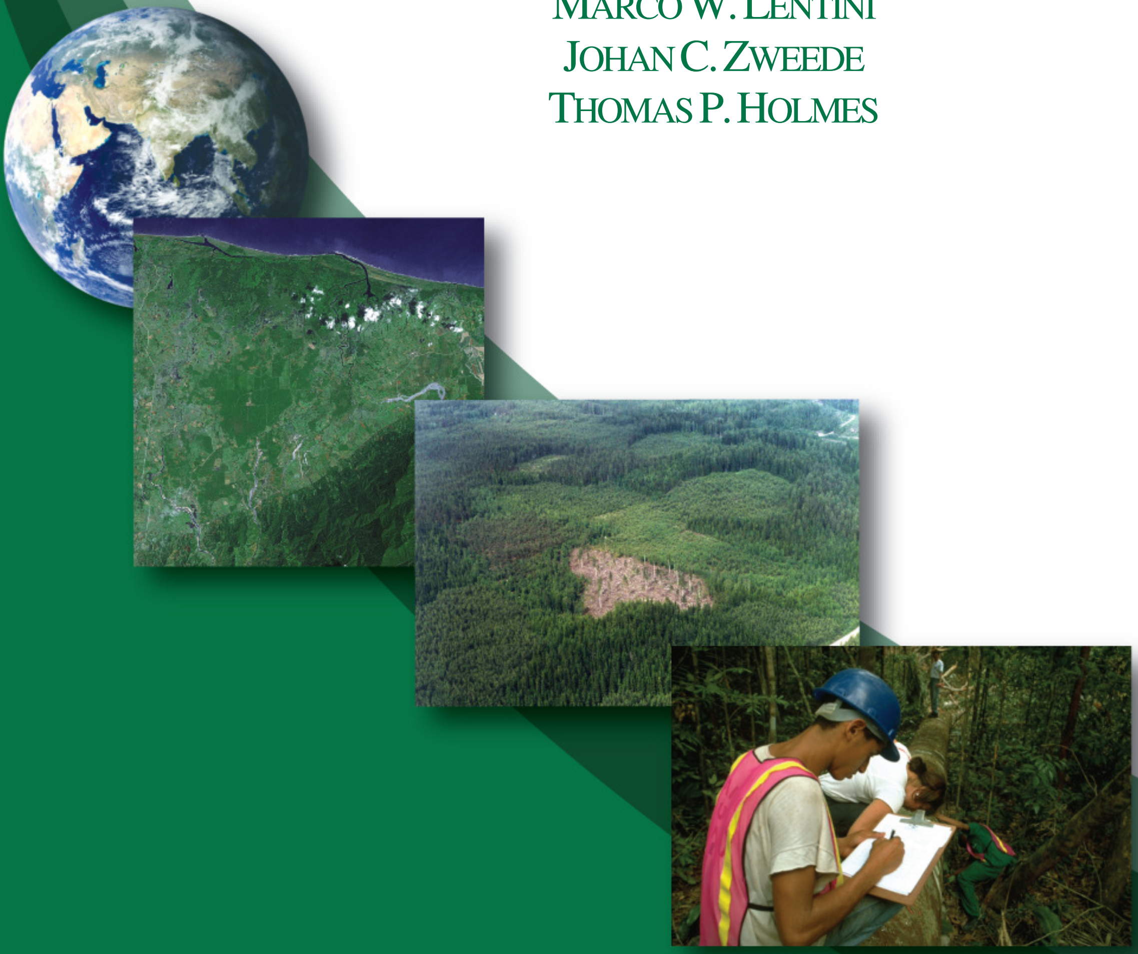
Forest Resources Assessment Working Paper 165

Case Studies on Measuring and Assessing Forest Degradation

Measuring Ecological Impacts from Logging in Natural Forests of the Eastern *Amazônia* as a Tool to Assess Forest Degradation

Marco W. Lentini
Johan C. Zweede
Thomas P. Holmes



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Sustainably managed forests have multiple environmental and socio-economic functions which are important at the global, national and local scales, and they play a vital part in sustainable development. Reliable and up-to-date information on the state of forest resources - not only on area and area change, but also on such variables as growing stock, wood and non-wood products, carbon, protected areas, use of forests for recreation and other services, biological diversity and forests' contribution to national economies - is crucial to support decision-making for policies and programmes in forestry and sustainable development at all levels.

Under the umbrella of the Global Forest Resources Assessment 2010 (FRA 2010) and together with members of the Collaborative Partnership on Forests (CPF) and other partners, FAO has initiated a special study to identify the elements of forest degradation and the best practices for assessing them. The objectives of the initiative are to help strengthen the capacity of countries to assess, monitor and report on forest degradation by:

- Identifying specific elements and indicators of forest degradation and degraded forests;
- Classifying elements and harmonizing definitions;
- Identifying and describing existing and promising assessment methodologies;
- Developing assessment tools and guidelines

Expected outcomes and benefits of the initiative include:

- Better understanding of the concept and components of forest degradation;
- An analysis of definitions of forest degradation and associated terms;
- Guidelines and effective, cost-efficient tools and techniques to help assess and monitor forest degradation; and
- Enhanced ability to meet current and future reporting requirements on forest degradation.

The Global Forest Resources Assessment programme is coordinated by the Forestry Department at FAO headquarters in Rome. The contact person is:

Mette Løyche Wilkie
Senior Forestry Officer
FAO Forestry Department
Viale delle Terme di Caracalla
Rome 00153, Italy
E-mail: Mette.LoycheWilkie@fao.org

Readers can also use the following e-mail address: fra@fao.org
More information on the Global Forest Resources Assessment programme can be found at: www.fao.org/forestry/fra

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Abstract

Sound forest management practices have been seen as an interesting strategy to ally forest conservation and rural economic development in *Amazônia*. However, the implementation of Reduced Impact Logging (RIL) techniques in the field has been incipient, while most of the Amazonian timber production is generated through predatory and illegal logging. Despite several improvements in remote sensing technologies focused on improved monitoring of illegal logging, a consolidated methodology to assess the quality in the implementation of management practices in the field – and therefore the level of degradation caused by harvesting – is needed. We present here a method based on a study conducted in 1996 at a forest site in Paragominas, Eastern *Amazônia*. The original objective of this study (Holmes *et al*. 2002) was to compare the costs and benefits of Conventional Logging (CL) with Reduced Impact Logging (RIL) under an economic perspective. This study created a method to assess ecological impacts caused by logging, which has been intensively replicated in the last 14 years in the field activities of the Instituto Floresta Tropical (IFT).

The method is based on two assessments:

(i) Damage to the residual trees in the forest stand;
(ii) Proportion of ground area disturbed during harvesting by heavy machines.

The first assessment is conducted through a simple evaluation of future-crop trees (DBH > 35 cm) in relation to damages in their crown and their boles which, combined, generate a classification of the general health status of the tree. The distribution of remaining trees in these health status classes characterizes the overall impact from harvesting over future crop trees.

The second, the assessment of ground area disturbed was executed by measuring the area of roads, log decks and skid trails (width and length).

In addition, the method includes a measurement of merchantable timber waste incurred during each type of logging. This included:
(a) Timber felled and not found by skidding crew or left in the forest because poor felling caused logs to split and lose merchantability;
(b) Timber left on the log deck;
(c) Timber wasted because cutting stumps were too high or due to poor bucking of felled logs.

Such relatively simple assessments proved to be efficient in measuring forest degradation caused by timber harvesting and revealed dramatic differences in the ecological damages caused by RIL and conventional logging.

Keywords: ecological impacts, timber waste, logging, RIL, *Amazônia*.

1. Introduction

Sound forest management practices have being faced as an interesting strategy to ally forest conservation and rural economic development in the tropics (Putz *et al*., 2001). However, up until this point, the implementation of RIL techniques in the field has being incipient (as shown in reports such as Sabogal *et al*., 2006 and ITTO, 2006), while most of the Amazonian timber production is generated through predatory and illegal logging (Lentini *et al*., 2005).

Illegal and predatory logging leads to the depletion of natural resources, which otherwise could be used to generate sustainable socioeconomic development. Instead, perverse economic incentives for extensive ranching and land grabbing have created an unsustainable model of local rural economic development known as boom-bust economy (Celentano & Veríssimo, 2007; Schneider *et al*., 2000). In this model, the socioeconomic development generated during the first decades since the beginning of the colonization process of Amazonian municipalities is ephemeral, and leads to a posterior collapse (Rodrigues *et al*., 2009).

Recent improvements in remote sensing technologies focused on improved monitoring of illegal logging, and are able today to monitor managed forestlands at a coarse scale, using general parameters of sound forest management (Monteiro *et al*., 2003). Despite such improvements, a consolidated methodology to assess the punctual quality in the implementation of management practices in the field – and therefore the level of degradation caused by harvesting – is needed. Brazil is establishing policies focused on implementing concession of public lands for forest management and the development of community forest management over a large extent of forestlands, and methodologies to assess degradation will be needed to plan, monitor, control and certify forestry operations. Such methods are also crucial considering the potential of Forest Management (FM) operations such as REDD (reduced emissions from deforestation and forest degradation) projects for maintaining superior amounts of carbon in the forest in comparison to other economic land uses (Putz *et al*., 2008).

The objective of the study is to present a method, applied in eastern Pará state since 1996, to assess degradation caused by logging based on the impact over future crop trees, ground area impacted by logging and timber wasted in harvesting activities.

Figure 1. Conventional harvesting systems do not utilize the best harvesting practices. (Source: FFT/IFT (2000))

2. Methodology

IFT is currently recognized as a specialized center to disseminate and improve sound forest management practices in the Brazilian Amazon. In the last 14 years, more than 3,500 forestry professionals and workers were trained in practical aspects of forest management, and at least 10,000 people were reached by events focused on raising awareness about forest management. IFT manages the Roberto Bauch Forest Management Center (RBMC), embedded in a private site owned by Cikel Brasil Verde, a FSC-certified company in Brazil, in which several experiments are conducted aiming to respond to critical questions for the improvement of forest management. IFT´s mission is motivated by the critical lack of trained professionals needed to address the challenge of expanding forest management in the newly established concession of public forests system (Lentini *et al.*, in press).

In 1996, an experiment was conducted at RBMC by researchers from the USDA - United States Forest Service and Brazilian NGOs (IFT and Imazon) focused on comparing the costs and benefits from RIL techniques in comparison to conventional logging practices through an economic perspective. The results of this study, originally published in Holmes *et al.* (2002), basically revealed smaller costs for timber produced under RIL practices considering the same harvesting intensity in a forestland harvested with RIL and one harvested with conventional logging. Such results were also confirmed by other experiments conducted in similar conditions in eastern Amazônia, such as those of Barreto *et al.* (1998). This experiment has, also, created a method to evaluate the degradation caused by logging over the forest, in a way to generate useful information to compare ecological impacts from RIL and CL. Today, typical results from these assessment methods are used by government as parameters for acceptable ecological impacts from logging in forest concessions and other forestlands managed by timber companies.

Study setting and site description

The experiment was conducted within RBMC in three 100 ha forest blocks, in which one was logged using RIL practices, one with conventional logging practices and one remained unlogged as a control area. The portion of RBMC used in the experiment is situated about 120 km southwest of Paragominas[1], Eastern Pará (3º35´ - 3º45´S; 48º15´ - 48º25´ W), on moderately undulating terrain formed from the residual tertiary plateau. The soils are oxisols with a distinct argillic horizon. Annual rainfall averages 2200 mm with a distinct dry season from June to November. Mean annual temperature is 28º C. The forest is classified as tropical moist, with more than 124 tree species, an abundance of lianas, and patches of emergent trees 50 m in height or more. Before harvesting, IFT conducted censuses of all commercial and potentially commercial trees on all blocks (trees > 35 cm D.B.H.) and established permanent plots representing 1 percent of the area in each of the blocks.

In the forest blocks harvested with RIL, harvesting was carefully planned beforehand. The census of all commercial trees was used to generate useful maps for planning of felling and skidding of logs. Lianas were cut at least one year before harvesting. Trees were cut using directional felling techniques by crews trained in such practices. Sawyers used a Stihl AV 51 chainsaw for felling and bucking operations. Skid trails were planned and laid out in the field in advance. A crawler tractor

1 Paragominas is a county in eastern Pará founded in the 1970´s, during the construction of the BR 010, a major federal road connecting the State capital (Belém) to the federal capital, Brasília. Paragominas was the main logging center in the Brazilian Amazon in the 1980´s, with more than 200 logging firms operating. However, in the 1990´s, logging started to collapse due to the exhaustion of raw material in the region provoked by years of conventional logging and conversion of degraded forests to extensive ranching (Lentini *et al.*, 2005).

(Caterpillar D6 SR) was used for construction of roads and log decks and a rubber tire skidder (Caterpillar 525) with winch and grapple was used for skidding operations. Logs were sorted and loaded on the log deck with a Caterpillar 938F Loader. Roads and log decks were constructed and skid trails were planned to be part of the permanent infrastructure to be available for the next harvest.

The conventional logging operation was conducted by a logger used to operating in the study region. His methods included the use of a harvesting crew with on-the-job-training, but no specific training in RIL methods. The CL operator used a crawler tractor (Caterpillar D6 Logger) with winch for constructing roads, log decks, and for skidding operations. A "tree hunter" (*mateiro*) worked with the sawyer to locate merchantable trees which would then be felled, without the use of directional felling techniques. Sawyers were paid on a piece rate, which typically encouraged rapid felling with little regard for waste and impacts on the residual stand. Skidding crews were not provided with precise information from felling crews regarding location of felled trees and therefore needed to search for logs. Logs were sorted and loaded using a Caterpillar 938F Loader.

Figure 2. Roads cause land use changes by providing market access for agricultural and forestry products. (Source: FFT/IFT (2000))

Measuring ecological impacts from logging

During the experiment conducted at the RBMC, Holmes *et al.* (2002) created a simple method to quantify degradation and ecological impacts provoked by logging based on three assessments:

(i) Damage to residual trees in the forest stand after logging;
(ii) Proportion of ground area disturbed during harvesting by heavy machines;
(iii) Timber waste incurred during harvesting as a consequence of ecological impacts on the forest or due to the lack of appropriate techniques.

Such relatively simple assessments proved to be efficient in measuring forest degradation caused by timber harvesting and revealed dramatic differences in the ecological damages caused by RIL and conventional logging. As mentioned before, this same method has been replicated several times for experimental and demonstrative purposes (i.e., in IFT´s practical course) since then. In fact, in 2009, IFT received some funds to replicate the comparative study of damages and timber waste using the same methodology.

Damage to residual trees

The assessment of damage to trees is conducted through a simple evaluation of future-crop trees in relation to damage in their crown and their boles which, combined, generate a classification of the general health status of the tree. This classification relates the severity of damage to bole and crown, cause of damage, and health status of each tree, using an adapted version of the method proposed by Johns *et al*. (1996), shown in Table 1. The distribution of remaining trees in these health status classes characterizes the overall impact from harvesting over future crop trees. Only commercial and potentially commercial tree species with good form and DBH > 35 cm are used in this measurement, since they represent trees that will be harvested in the second cutting cycle. The census was conducted about 20 months after harvest, so damage due to harvest-gap induced windthrow was included. The same operational procedure and the same assessment team were used for both RIL and CL areas. In the field, trees were located using an inventory list with coordinates, common and scientific names, tree numbers, and diameters. Two assistants helped locate trees on the list, while two technicians assessed and recorded damage.

Table 1. Classification of severity of damage to future crop trees in relation to crown damage, bole damage and cause of damage.

Severity class	**Crown damage**	**Bole damage**	**Cause of damage**	**Health class**
0	No damage, complete crown	No damage	-	No damage
1	Minor damage, i.e. < 1/3 of crown damaged	Minor damage to < 1,500 cm^2 of bark	Felling	Clear signs of recovery
2	Moderate damage, i.e. > 1/3, but less than 2/3 of crown destroyed	Minor damage to > 1,500 cm^2 of bark	Skidding	No sign of recovery or death/decay
3	Severe damage, i.e. crown smashed	Moderate damage, i.e. deeper than bark, but < 1,500 cm^2 in area	Road building	Clear signs of death or decay (e.g. insect of fungal attack)
4	N/A	Severe damage to area > 1,500 cm^2, e.g. a major tear or broken branch	Log deck construction	N/A
5	N/A	Irreversible damage (clearly dead or dying), e.g. smashed bole	Natural causes (unrelated to harvest activities)	N/A

Ground area disturbed

The assessment of ground area disturbed, measures the total impact of heavy machinery on the forest floor. It was expected that RIL practices, designed to reduce the impact over the soil, could generate smaller disturbance, which is expected to yield greater future forest productivity because less regeneration is destroyed during harvest operations and less mineral soil exposed. The assessment is made in the field, by measuring the total area of roads, log decks and skid trails established for harvesting. The same technician used a 50 metre tape to measure the length and width of every road, skid trail and log deck in both harvest areas. The direction of every infrastructure measured was recorded with a compass to permit mapping these features in the office. The surface areas of these features were calculated by multiplying length and wide.

Although compaction was not measured, disturbance severity was estimated. Every 30 meters along all skid trails, an observation was made to evaluate whether mineral soil was exposed and if the litter layer or vegetation remained. The sampling unit was a single line across the width of the skid trail. Overall disturbance was the percentage of lines with exposed soil.

Timber wasted

Finally, total volume of merchantable timber wasted in each type of logging was measured. The volume of timber wasted is measured as the difference between the potential volume recovered under "ideal" logging and the actual volume recovered. Causes of timber wasted can be listed as a consequence of: (a) timber felled and not found by skidding crew or left in the forest because poor felling caused logs to split and lose merchantability; (b) timber left on the log deck; (c) timber wasted because cutting stumps were too high or due to poor bucking of felled logs. A crew of IFT technicians measured volume of timber waste by measuring the area and the length of timber portions that could be harvested but were left in the forest.

While damage to residual trees and the impacts caused by heavy machinery represent an inefficiency in terms of the forest productivity and future value of the forest, timber waste and the direct damages caused by machinery represent an immediate measure of inefficiency, because they are associated with direct and indirect costs (stumpage costs, felling, bucking, skidding and log deck construction) which are diluted to the total harvested volume.

3. Results

The original experiment conducted at RBMC demonstrated a net income from RIL 19 percent higher than conventional logging, mainly as a consequence of:

- Higher productivity in skidding and log deck operations (39 percent),
- Larger reduction in all fixed and variable costs related to harvesting (12 percent) and
- A decrease in the timber wasted after logging (78 percent).

It is important to note that such results are based on the same volume of timber harvested in each treatment, or approximately 25 m^3/ha. Further details about comparative costs of RIL and CL are shown in Holmes *et al*. (2002). For IFT, this experiment revealed that the main constraints for the adoption of sound forest management practices were not related to costs, but to the lack of trained professionals and workers and the distorted perception from forest entrepreneurs and decision-makers regarding the benefits of forest management, guiding its work until today.

Damage to residual trees

Felling was revealed as the most important driver of damages to residual trees, and for this reason it is shown separately in Table 2. Felling accounted for 98 percent of human-induced damages on the CL block and 96 percent of human-induced damage on the RIL block.

Damages caused by felling which caused the death of residual trees were more than two times higher in CL than in RIL. In CL, every 100 felled trees caused the death of 34 remaining trees, while in the RIL treatment this value was only 16. Considering other harvesting activities, CL caused the death of 4 remaining trees for every 100 trees harvested; and RIL only 1 (Table 2).

Table 2. Potential future crop trees damaged per tree harvested by felling and other activities. Proportion of remaining trees damaged by felling and other harvesting activities in the CL and RIL operations, from commercial and potentially commercial species, at RBMC, in 1996. Actual numbers of trees are shown in parentheses.

Health class	**Conventional Logging**		**Reduced Impact Logging**	
	Felling Damage	**Damage from other activities**	**Felling Damage**	**Damage from other activities**
Recovering	0.14 (54)	0.11 (43)	0.24 (80)	0.17 (57)
No sign of change	0.16 (63)	0.05 (21)	0.18 (58)	0.05 (17)
Dying	**0.34 (136)**	**0.04 (16)**	**0.16 (52)**	**0.01 (2)**
Total Impacted	**0.64 (253)**	**0.20 (80)**	**0.58 (190)**	**0.23 (76)**

Ground area disturbed by logging

The ground area disturbed by heavy machinery on the CL block was nearly twice the ground area disturbed by RIL operations (Table 3). On average, heavy machinery disturbed about 10 percent of the ground area in the CL block versus about 5 percent of the ground area in the RIL block. If we consider only the area disturbed per tree harvested, CL presented 60 percent more disturbance than the RIL treatment.

In addition, the experiment showed that 100 percent of the CL skid trails were cleared to mineral soil, whereas less than 10 percent of the RIL skid trails had mineral soil exposed. Holmes et al. (2002) note that cumulative disturbance over time in conventional logging tend to intensify, since forest infrastructure (roads, log decks and skid trails) tend to be recognized as permanent features in RIL, and will be used during the second harvest, while forest infrastructure in CL will be built again in the second harvest. In the first case, cumulative financial benefits will be also larger, since permanent infrastructure will amortize the forest entrepreneur investment over more than one harvest.

Table 3. Ground area disturbed (m^2 per tree harvested and hectares per 100 ha block) by RIL and CL operations, at RBMC, in 1996. In the CL operation, 397 trees were harvested; 328 trees were harvested in the RIL operation.

Activity	**Conventional logging**		**Reduced-impact logging**	
	m^2 / tree harvested	**ha / 100 ha block**	**m^2 / tree harvested**	**ha / 100 ha block**
Secondary roads	34	1.35	20	0.65
Log decks	26	1.05	19	0.63
Skid trails	193	7.66	120	3.90
Total	**253**	**10.05**	**159**	**5.18**

Timber waste provoked by logging

RIL activities were effective in reducing the amount of timber wasted relative to the CL operation (Table 4), resulting in a clear gain in timber utilization efficiency. Timber wasted in the CL block was almost a quarter (23.9 percent) of the standard harvest volume. RIL caused a total waste of 7.6 percent of merchantable timber.

Most of the timber wasted in the forest was due to improper bucking of logs (CL = 1.97 m^3/ha vs. RIL = 0.85 m^3). On the CL block, the second most important source of waste was logs not found by skidding operation (0.96 m^3/ha). On the RIL block, only 1 log, representing 0.06 m^3/ha, was not found by the skidding crew due to an eventual operator's mistake. Logs split due to improper felling accounted for 0.87 m^3/ha on the CL block and 0.31 m^3/ha on the RIL block. Cutting stumps too high wasted 0.28 m^3/ha on the CL block and 0.10 m^3/ha on the RIL block. Finally, timber harvested but left on the log deck amounted to 1.97 m^3/ha on the CL block and 0.60 m^3/ha on the RIL block.

Table 4. Volume of timber wasted in the forest and on the log decks in the CL and RIL blocks, at RBMC, in 1996.

Source	**CL waste (m^3/ha)**	**RIL waste (m^3/ha)**
High stumps	0.28	0.10
Split logs	0.87	0.31
Bucking waste	1.97	0.85
Logs lost	0.96	0.06
Total forest	**4.08**	**1.32**
Log deck	1.97	0.60
Total	**6.05**	**1.92**

4. Discussion

The main purpose of this paper was to present a simple method to assess forest degradation and ecological impacts caused by logging based on assessments of ground floor disturbance, damage of residual trees after harvesting and timber waste. It is a very relevant methodology considering the perspectives of forest management to expand as the most viable economic alternative in inland Amazonian regions, strengthened by the current efforts from government and society to protect and conserve public production forests in a concession system. Despite current development of remote sensing techniques able to identify in a coarse scale the overall occurrence of sound forest management indicators, field based methods are still necessary to evaluate the quality of forest operations and their ecological impacts over the forest. The methodology presented in this paper was replicated for more than a decade in eastern Pará forestlands. It is also being disseminated through practical courses promoted by IFT in its Forest Management Center.

It is still necessary to replicate the method in other regions in *Amazônia*, taking into account the diversity of physical conditions such as forest type, species diversity, logging intensity, equipment, technological alternatives for different scales (floodplain forests, community forest management, middle and large-scale industrial logging) and seasonality of logging. Such efforts would create useful parameters for technicians, public planners, decision makers, independent forest professionals, researchers and governmental agents to plan, monitor, license and certify forest operations based on degradation provoked by logging. Considering the potential perspectives for FM operations to be included in REDD (reduced emissions from deforestation and forest degradation) projects, it would also create useful standards to evaluate specific projects.

5. Conclusions

The method used to evaluate forest degradation and ecological impacts from logging presented in this paper has a large potential to be disseminated to other regions in *Amazônia* and surrounding countries. As main advantages, we can cite its simplicity and viability to be used in different contexts. Measurement of roads, log decks and skid trails can be improved in large scale enterprises using recent GPS technology, in a way to gain productivity in these assessments. However, the methodology still requires validation in other forest types and technological alternatives, mainly considering community forest management operations, to be useful to create standards to measure degradation over large extents of forests and socio-cultural contexts.

The method could be disseminated and discussed with other FM centers, training centers, universities and forestry foment organizations and agencies in a way to improve its operational procedures, disseminating the method to other tropical regions, and generating parameters to permit comparisons over large extents of forestry operations.

Figure 3. Minimizing the width of forest roads reduces costs and decreases ecological damage. (Source: FFT/IFT (2000))

A. B.

Figure 4. Two photos showing the difference between areas where Reduced Impact Logging (A) and Conventional Logging (B) have been undertaken. (Source: FFT/IFT (2000))

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