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ScienceDirect
Forest Ecology and Management 237 (2006) 83–93
Forest Ecology and Management
www.elsevier.com/locate/foreco

A comparison of damage due to logging under different forms of resource access in East Kalimantan, Indonesia

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Received 9 February 2004; received in revised form 2 June 2006; accepted 21 September 2006

Abstract

Recent changes in forest resource access arrangements have important implications for the future extent and quality of natural forest in Indonesia. This study quantified and compared total harvested and damaged trees after logging operations carried out in East Kalimantan, Indonesia under two types of arrangements: 20-year commercial selective logging concessions, known as *Hak Pengusahaan Hutan* (HPH) and 1-year harvest permits intended for local communities, known as *Ijin Pemungutan dan Pemanfaatan Kayu* (IPPK). Sample plots of 20 ha were established in areas previously harvested by HPH and IPPK. Harvest levels were lower than those documented in other logging studies in Borneo, although it is possible that missing and therefore uncounted stumps of harvested trees in cleared areas (i.e. log landings and roads) and larger plots size may have underestimated harvest levels. Significant differences were found between HPH selective logging and IPPK permit holders (1 trees ha^{-1} and 4 trees ha^{-1}, respectively). It was found that IPPK permit holders harvested a larger percentage of trees below 50 cm dbh than did HPH logging (>25% as compared to 3%, respectively). IPPK permit holders operations also damaged twice as many residual trees below 50 cm dbh per unit area as did HPH harvests. However, HPH produced higher levels of damage per unit volume and number trees harvested, in terms of skid trail length, number of trees damaged, and canopy opening. The sum of the harvested and damaged trees, which may be lost from future harvest due to rot and mortality after harvesting, was significantly different under short-term permit holders and selective logging concessionaires (28 trees ha^{-1} versus 9 trees ha^{-1} in primary forest; 39 trees ha^{-1} versus 28 trees ha^{-1} in logged-over forest). Future harvest potential of the forest may be significantly lower with the influence of IPPK logging system, in terms of harvesting practices and logging damaged to the forest stands.

Keywords: Canopy opening; Concession; Decentralization; Dipterocarps; Harvest permits; Skidding; Tropical forest

1. Introduction

Regional autonomy laws, including the decentralization of responsibilities for the forestry sector, may have important implications for the future extent and quality of natural forest in Indonesia. Until 1999, logging in Indonesia was carried out exclusively under large industrial forestry concessionaires, known as *Hak Pengusahaan Hutan* (HPH). These operators, granted 20-year selective logging concessions on national forest lands, are supposed to follow the *Tebang Pilih Tanam Indonesia* (TPTI), the guidelines for Indonesian's selective cutting and replanting system (Departemen Kehutanan, 1993), with 35 years polycyclic harvested system. A second system of forest resource access, initiated in 2000, is called *Ijin Pemungutan dan Pemanfaatan Kayu* (IPPK). These annual permits for commercial logging were intended to provide timber-harvesting rights to local communities, that lie outside the areas defined by the central government as permanent forest estates, and are granted by district governments under Government regulation PP nos. 62/1998 and 6/1999, delegating partial authority in the forest sector to the regions. In practice, however, many have been granted within the boundaries of HPH concessions to private investors, mostly logging companies (Barr et al., 2001). They are being granted in almost all districts in Kalimantan, Indonesia. Between April 2000 and May 2001, the district government of Malinau, East Kalimantan had issued 40 IPPKs of 100–3000 ha

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0378-1127/$ – see front matter
doi:10.1016/j.foreco.2006.09.079

each, covering an aggregate area of 59,850 ha (Pemda Malinau, 2001).

Harvesting rules to follow by these systems were essentially the same, which are supposed to sustain timber yield on a long-term basis. In HPH, activities related to forest inventories of commercial and harvestable trees, logging planning, cutting block mapping, and logging road construction should done prior to the logging. However, the IPPK system was not required to maintain work plans, due to limited time and area allocated for harvesting. The skid trail network was established during timber extraction, according to the position of trees to be felled. In most cases, loggers worked unsupervised but trees to be felled were marked. Crawler tractors (Caterpillar D7G, or Komatsu D60E), with a >4 m wide blade, were generally used for both road opening and log extraction. Owing to market conditions, which most of the harvested timber are used for plywood, harvesting in HPH was limited to trees larger than 50 cm dbh to ensure future-harvesting cycle remains. Whereas, in IPPK the diameter limit is much more flexible and can be lower, because local community also used sawn timber for local sawmills. However, our observation prior to the study showed that harvesting practices implemented by these two systems, as well as the damaged to the residual stand were essentially the same, due to TPTI violations by HPH. Moreover, after the IPPK system was put in place, we also noticed that several HPH operations were operating like IPPK. There were several reasons—social, culture, politic, and economic to identify why and how these practices happen (Barr et al., 2001; Resosudarmo, 2002). Furthermore, after

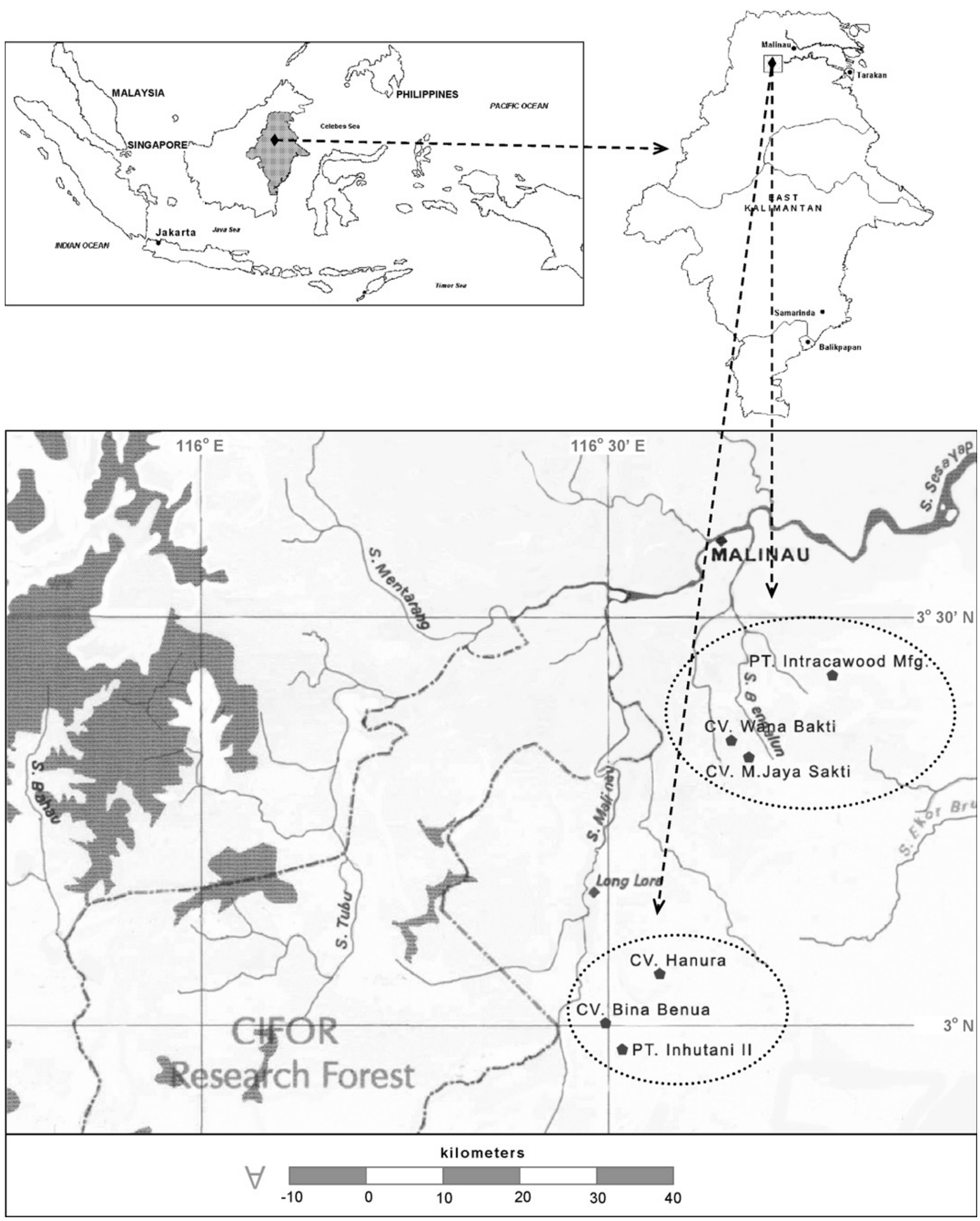

Fig. 1. Map of Indonesia archipelago (top left), East Kalimantan province (top right), and map of the study area in Malinau (bottom).

decentralization the percentage of community that received financial and in-kind benefits from the new system significantly increased. However, the conflicts between communities over land claims and borders occurred also increased afterwards (Palmer and Engel, 2005).

The main objective of this study was to evaluate post-harvest damage from road construction, felling activities and skidding operations in areas harvested under short-term IPPK permits as compared to longer-term HPH selective logging. Furthermore, we want to identify the influence of this IPPK new system to the earlier HPH system that granted by the Ministry of Forestry, in terms of harvesting practices and logging damaged to the forest stands. We hypothesized that harvesting practices under selective logging HPH system, which more regulated, resulted in similar logging damage to harvesting under the IPPK permit holders that incorporate no logging guidelines.

2. Study sites

The study was carried out in Malinau District, East Kalimantan (Fig. 1) located between 116°29′ and 116°44′ East Longitude and 2°59′ and 3°28′ North Latitude. The forest type is predominantly lowland and sub-montane tropical forest, dominated by trees of the *Dipterocarpaceae* family. In most study areas, altitude ranges from 100 to 200 m a.s.l., with flat to undulating terrain (0–8% slopes), although some areas are steeper (8–15% slopes). The monthly rainfall varies between 200 and 400 mm, totalling approximately 4000 mm annually (Machfudh, 2001).

The sample areas were selected based on information regarding accessibility (i.e. road conditions and equipment) obtained from concessionaire management and government office staff. Our preliminary evaluation of companies operating in Malinau revealed that several selective logging concessionaires licenses were stopped for various reasons: expiration, topography constraints, or conflict with local communities. We were therefore only able to evaluate two selective logging concessionaires, one belonging to a state-owned company and the other to a privately owned company, with annual cutting areas of 700 and 5000 ha, respectively. Three short-term permit holder operators and a subcontractor of a selective logging concessionaires were also evaluated. Logging activities for all operators took place mostly in early 2001.

3. Methods

3.1. Sample plot establishment

Two forest types were evaluated in this study: (1) primary forest, which had more big trees and had never been logged and (2) logged-over forest, which had been logged under a prior selective logging concessionaires and had fewer big trees. The state-owned selective logging HPH and one IPPK holders were harvesting in primary forest, while the privately owned selective logging HPH and the remaining IPPK holders had harvest permits for logged-over forest. Six 20 ha sample plots were established in November 2001 and January 2002 in forests harvested by each operator (36 plots in total). For most IPPK holder operators, which lack maps, we established our plots within the boundaries of the cutting blocks based on information from camp managers and village staff. Imaginary boundaries for each plot were established by mapping roads and skid trails using a GPS Trimble Geo Explorer-3. Data on harvest intensity and damage to residual trees were collected inside the imaginary plot boundaries along logging roads, skid trails, and within gaps produced by felling.

3.2. Measurement of harvest intensity

Tree stump counts and measurements were used to estimate harvests, as has been done elsewhere (Chhetri and Fowler, 1996). Stumps were counted and measured along the logging roads and skid trails, and within felling gaps, in each sample plot. Diameters were measured at the top of the stump using a diameter tape. We converted the diameter at the estimated stump height (dsh) to dbh using an allometric equation derived from tree measurements in the same area (Iskandar et al., 2003):

$$\text{dbh} = 0.518 + 0.966 \times \text{dsh} \quad (\text{S.E.} = 0.850;\ R^2 = 0.998)$$

3.3. Logging damage assessment

In each sample plot, skid trails and logging roads were mapped and measured using GPS. To inventory damage in areas affected by harvest operations, we measured the canopy opening and felling impact zones along roads and skid trails using a Laser Range-finder Impulse 200, a hand-held laser ranging instrument that allow to quickly and conveniently measure distances, height, and vertical angles (Anonym, 1998). To estimate the width of the open areas, we measured the distance in eight directions from the centre of the plot to each edge.

Damage to residual trees from logging operations was assessed along skid trails and logging roads using a system applied in a previous CIFOR experiment (Sist and Nguyen-The, 2001). All injured trees >10 cm dbh were measured and recorded, and classified according to six main classes of damage: (1) bark-wood damage; (2) leaning; (3) crown injury; (4) broken trunk-alive; (5) broken trunk-dead; (6) uprooted.

3.4. Stratification and data analysis

To compare rates of post-harvest damage, we stratified the 36 plots according to the operator type and type of forest, as follows: (1) in primary forest, HPH $n = 6$ plots (PT. Inhutani II), subcontractor $n = 6$ plots (CV. Bina Benua), IPPK $n = 3$ plots (CV. Hanura) and (2) in logged-over forest, HPH $n = 6$ plots (PT. Intracawood), and IPPK $n = 15$ plots (CV. Hanura, CV. Malinau Jaya Sakti, and CV. Wanabakti).

Data on tree damage were analysed per unit area or length of skid trail or road, and per number and volume (m^3) of harvested trees, using SPSS (1999, Version 9.0.1). A comparison of damage levels used one-way analyses of variance (ANOVA).

Characteristics of damage and frequency of stumps by diameter class were compared using a non-parametric test for two independent samples (Mann–Whitney). For all statistical comparisons we used a confidence level of $p = 0.05$.

4. Results

4.1. Harvesting practices by HPH

Harvesting practices by selective logging HPH in primary forests were operated in two systems, first done by HPH logging staff and secondly was done by HPH's subcontractor, which equipped with better machinery. Initial analyses, however, revealed that harvests by the selective logging HPH's subcontractor were significantly higher than by HPH logging staff (3 stumps ha^{-1} versus 1 stumps ha^{-1}, respectively). Of these stumps, 10% and 3%, respectively, were below the TPTI diameter limit. There were no significant differences between HPH's subcontractor and HPH in skid trail length (52 m ha^{-1} versus 34 m ha^{-1}) and road length (27 m ha^{-1} versus 25 m ha^{-1}). However, HPH's subcontractor logging resulted in higher rates of damage compared to HPH. Significant differences were found for the number of damaged trees (32 trees 100 m^{-1} versus 20 trees 100 m^{-1}, respectively) and total canopy openings (0.3 ha ha^{-1} versus 0.1 ha ha^{-1}, respectively). The sum of harvested and damaged trees on HPH selective logging was also significantly higher for the HPH's subcontractor among all diameter classes, and twice as high for trees <50 cm as on selective logging by HPH logging staff (19 trees ha^{-1} versus 7 trees ha^{-1}, respectively).

When HPH's subcontractor harvesting practices in primary forest compared to IPPK, there were no significant differences revealed in harvest intensities (3 stumps ha^{-1} versus 4 stumps ha^{-1}, respectively), skid trail length (52 m ha^{-1} versus 49 m

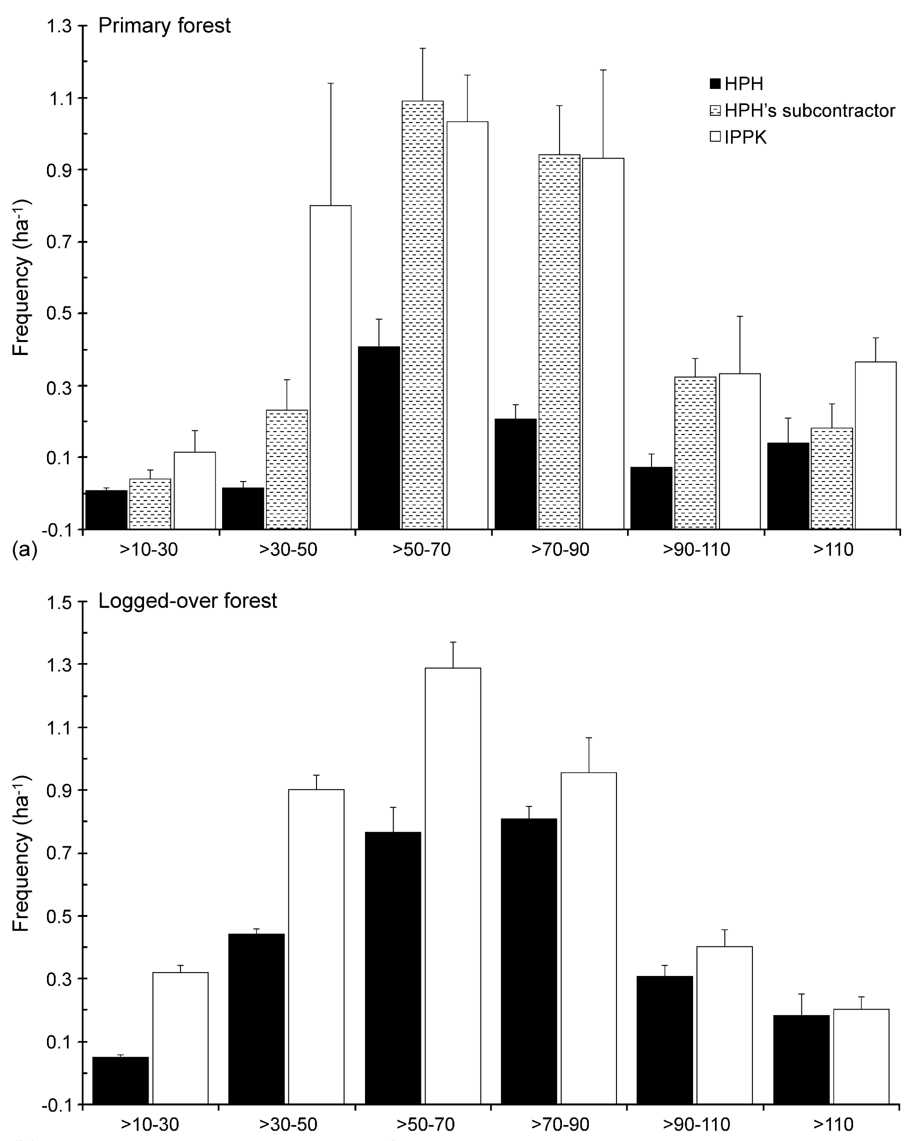

Fig. 2. Frequency and distribution of stump diameters of trees harvested (stumps ha^{-1}) by logging concessionaires (HPH), HPH's subcontractor, and short-term permit holders (IPPK) in both forest types.

ha^{-1}), logging road length (27 m ha^{-1}, respectively), number of damaged trees (32 trees 100 m^{-1} versus 38 trees 100 m^{-1}), and total canopy openings (0.3 ha ha^{-1}, respectively). Whereas, when HPH logging staff harvesting practices compared to the IPPK, there were also no significant difference in terms of skid trail and logging road length. However, significantly differences were find in terms of harvest intensities (1 stumps ha^{-1} versus 4 stumps ha^{-1}), number of damaged trees (20 trees 100 m^{-1} versus 38 trees 100 m^{-1}), and total canopy openings (0.1 ha ha^{-1} versus 0.3 ha ha^{-1}, respectively). These differences led us to exclude areas logged by the HPH's subcontractor from the comparison between HPH and IPPK permit holders logging operation in primary forest. More detail description of the harvesting practices by HPH and IPPK in primary forest will be presented in Section 5.

4.2. Harvest intensity

Harvest intensities in primary forest were 1 and 4 stumps ha^{-1}, respectively, for selective logging HPH and IPPK permit holders. In logged-over forest, harvest intensities were relatively similar for logging by HPH and IPPK permit holders (3 stumps ha^{-1} versus 4 stumps ha^{-1}, respectively). In primary forest, IPPK permit holders left more stumps per hectare for all diameter classes and more stumps in diameter classes 30–50, 50–70 and 70–90 cm, than logging HPH (Mann–Whitney test; Fig. 2a). IPPK logging in logged-over forest resulted in more stumps per hectare than HPH selective logging for all diameter classes (Fig. 2b) and significantly more stumps at class 10–30 cm.

In both forest types, IPPK permit holder operations cut more trees with diameters smaller than the TPTI diameter limit (50 cm) than did HPH selective logging. In primary forest, the percentages for HPH and IPPK logging were 3 and 26%, while in logged-over forest they were 19 and 30%, respectively.

4.3. Logging road and skid trail and length

IPPK permit holder operations resulted in higher lengths of skid trails and roads per hectare compared to HPH logging in primary forest, and higher skid trail length in logged-over forest (Table 1A). However, differences in road length per hectare between IPPK permit holders and HPH logging were not significant in either forest type. The only significant difference between the two types of operators was for skid trail length in logged-over forest (63 m ha^{-1} for IPPK versus 43 m ha^{-1} for HPH).

When analysed per harvested tree, IPPK operations produced lower lengths of skid trails and roads per tree harvested than HPH logging in both forest types (Table 1B). However, the difference was significant only for road length in primary (7 m versus 32 m per stump, respectively) and in logged-over forest (9 m versus 14 m per stump, respectively). IPPK permit holders also built lower lengths of road per unit volume (m^3) harvested compared to HPH logging in both forest types, and lower lengths of skid trails in primary forest (Table 1C). However, the only significant difference was in logging road length in primary forest (1 m versus 3 m per m^3 for IPPK and HPH logging, respectively).

Table 1
Comparison of skid trail and logging road length between HPH, HPH's subcontractor, and IPPK

	HPH (mean ± S.E.)	IPPK (mean ± S.E.)	HPH's subcontractor (mean ± S.E.)
(A) Per unit area (ha^{-1})			
Primary forest			
Skid trails length (m ha^{-1})	33.6 ± 5.9 a	48.9 ± 13.5 a	51.6 + 8.8 a
Logging road length (m ha^{-1})	24.9 ± 4.4 a	27.0 ± 6.4 a	27.3 + 2.8 a
Logged-over forest			
Skid trails length (m ha^{-1})	43.4 ± 5.9 a	62.7 ± 5.2 b	n.d.
Logging road length (m ha^{-1})	34.2 ± 1.9 a	29.8 ± 1.8 a	n.d.
(B) Per number of trees harvested			
Primary forest			
Skid trails length (m)	41.4 ± 8.2 a	14.1 ± 4.5 b	18.3 ± 1.7 b
Logging road length (m)	31.5 ± 7.1 a	7.4 ± 1.4 b	11.1 ± 2.1 b
Logged-over forest			
Skid trails length (m)	17.4 ± 2.7 a	18.6 ± 2.4 a	n.d.
Logging road length (m)	13.5 ± 0.5 a	8.9 ± 1.3 b	n.d.
(C) Per volume (m^3) of trees harvested			
Primary forest			
Skid trails length (m m^{-3})	3.4 ± 0.7 a	1.2 ± 0.2 b	1.7 ± 0.1 b
Logging road length (m m^{-3})	2.5 ± 0.4 a	0.7 ± 0.2 b	1.1 ± 0.2 b
Logged-over forest			
Skid trails length (m m^{-3})	1.6 ± 0.2 a	2.3 ± 0.4 a	n.d.
Logging road length (m m^{-3})	1.3 ± 0.1 a	1.1 ± 0.2 a	n.d.

Plots for HPH and IPPK in primary forest (6 and 3 plots, respectively) and in logged-over forest (6 and 15 plots, respectively).
n.d.: no data available. Means followed by the same letter are not significantly different by ANOVA at $p < 0.05$.

Table 2
Comparison of logging damage between HPH, HPH's subcontractor and IPPK logging operations

	HPH (mean ± S.E.)	IPPK (mean ± S.E.)	HPH's subcontractor (mean ± S.E.)
(A) Per unit length or area			
Primary forest			
Trees damaged per length ($100\ m^{-1}$)	19.9 ± 4.1 a	38.0 ± 6.1 b	32.2 ± 2.6 b
Total canopy opening ($ha\ ha^{-1}$)	0.11 ± 0.02 a,*	0.31 ± 0.01 b	0.30 ± 0.04 b
Logged-over forest			
Trees damaged per length ($100\ m^{-1}$)	32.0 ± 2.0 a,*	43.3 ± 2.2 b	n.d.
Total canopy opening ($ha\ ha^{-1}$)	0.19 ± 0.14 a	0.32 ± 0.03 b	n.d.
(B) Per number of trees harvested			
Primary forest			
Number of trees damaged	13.6 ± 3.3 a	7.8 ± 0.8 a	9.5 ± 1.2 a
Total canopy opening (m^2)	1506 ± 387 a	865 ± 59 a	1099 ± 84 a
Logged-over forest			
Number of trees damaged	9.9 ± 1.1 a	11.2 ± 1.1 a	n.d.
Total canopy opening (m^2)	757 ± 77 a	904 ± 105 a	n.d.
(C) Per volume (m^3) of trees harvested			
Primary forest			
Number of trees damaged	1.2 ± 0.3 a	0.7 ± 0.1 a	0.9 ± 0.1 a
Total canopy opening ($m^2\ m^{-3}$)	120.4 ± 18.6 a	77.1 ± 7.6 a	102.2 ± 8.0 a
Logged-over forest			
Number of trees damaged	0.9 ± 0.1 a	1.3 ± 0.2 a	n.d.
Total canopy opening ($m^2\ m^{-3}$)	72.2 ± 7.9 a	114.2 ± 22.7 a	n.d.

Plots for HPH and IPPK in primary forest (6 and 3 plots, respectively) and in logged-over forest (6 and 15 plots, respectively).
n.d.: no data available. Means followed by the same letter are not significantly different by ANOVA at $p < 0.05$, and symbol * are significant difference at $p < 0.01$.

4.4. *Logging damage to residual trees*

In both forest types, IPPK permit holders damaged more trees per hectare than HPH logging. There were significant differences in primary forest for diameter classes 10–30 cm (17 trees ha^{-1} versus 4 trees ha^{-1}, respectively), 30–50 cm (8 trees ha^{-1} versus 4 trees ha^{-1}, respectively), and 50–70 cm (2 trees ha^{-1} versus 1 trees ha^{-1}, respectively). Moreover, 82% of trees damaged by IPPK operations were less than 50 cm dbh. In logged-over forest, most damaged trees were in diameter classes 10–30 cm (24 trees ha^{-1} versus 13 trees ha^{-1}, respectively) and 30–50 cm (12 trees ha^{-1} versus 8 trees ha^{-1}, respectively), which represented 86% of all damaged trees.

Significant differences were found between IPPK permit holders and HPH logging operations in both forest types with regards to the number of damaged trees and area of canopy opening per unit length or area (Table 2A). However, there were no significant differences between HPH's subcontractor and IPPK in those two categories of damaged in primary forest. Whereas, significant difference was found between HPH's subcontractor and HPH logging staff. In primary forest, values were 38, 32, and 20 trees $100\ m^{-1}$ for damaged trees, with 0.3, 0.3, and 0.1 ha ha^{-1} for canopy opening, for IPPK, HPH's subcontractor, and HPH, respectively. In logged-over forest, values were 43 trees $100\ m^{-1}$ versus 32 trees $100\ m^{-1}$ for damaged trees, and 0.3 ha ha^{-1} versus 0.2 ha ha^{-1} for canopy opening, respectively.

When damage was analysed per number and volume of trees harvested (Table 2B and C), no significant differences were found between types of operators in either forest type. However, HPH logging operations produced higher levels of damage compared to IPPK in primary forest, while in logged-over forest IPPK logging produced higher levels of damage compared to HPH.

4.5. *Category of damage to residual trees*

In primary forest, for both operators, the most common types of harvesting damage to residual trees were crown injury, broken trunk-dead, and uprooted (Table 3). Along skid trails and within felling gaps, the number of damaged trees was similar between HPH and IPPK logging. However, along roads IPPK damaged significantly more trees than HPH logging in the categories broken trunk-alive (4.9 trees $100\ m^{-1}$ versus 1.1 trees $100\ m^{-1}$, respectively), broken trunk-dead (11.8 trees $100\ m^{-1}$ versus 1.8 trees $100\ m^{-1}$, respectively), and uprooted (25.7 trees $100\ m^{-1}$ versus 1.4 trees $100\ m^{-1}$, respectively). The common categories of damage in logged-over forest were crown injury and uprooted (Table 4). However, the only significant difference was in the number of uprooted trees along roads (15 trees $100\ m^{-1}$ versus 5 trees $100\ m^{-1}$ for IPPK and HPH logging, respectively).

We hypothesized that trees suffering four of the categories of damage (leaning, crown-injured, broken trunk, and uprooted) would either rot or die, and thus be lost from the population of future harvest trees. In primary forest, IPPK permit holders would thus lose significantly more trees from this population than HPH logging, from all diameter classes (28 trees ha^{-1} versus 9 trees ha^{-1}, respectively, Fig. 3a). More than 80% of these trees were in diameter classes 10–30 cm (15 trees ha^{-1} versus

Table 3
Trees damaged per 100 m length of skid trail or logging road (trees 100 m^{-1}) due to HPH and IPPK logging in primary forest

Types of damage/ locations	Skid trail + felling gap		Logging road	
	Mean ± S.E.	Range	Mean ± S.E.	Range
HPH (n = 6 plots)				
Bark and wood damage	2.3 ± 0.5	0.1–3.5	0.4 ± 0.2	0.0–1.3
Leaning	3.9 ± 1.5	0.1–10.4	0.6 ± 0.3	0.0–1.7
Crown injury	8.2 ± 1.7	2.8–14.6	3.4 ± 1.5	0.0–9.3
Broken trunk-alive	0.6 ± 2.4	1.3–4.9	1.1 ± 0.5*	0.0–3.4
Broken trunk-dead	5.5 ± 1.4	1.3–11.1	1.8 ± 0.8*	0.0–5.4
Uprooted	7.6 ± 3.2	1.0–22.3	1.4 ± 0.6*	0.0–4.1
IPPK (n = 3 plots)				
Bark and wood damage	2.4 ± 0.5	1.5–3.0	0.5 ± 0.2	0.0–0.9
Leaning	1.7 ± 0.2	1.5–2.1	0.7 ± 0.3	0.0–1.2
Crown injury	8.2 ± 2.5	3.2–11.2	9.1 ± 1.2	7.1–11.2
Broken trunk-alive	2.8 ± 1.1	0.7–4.0	4.9 ± 0.9*	3.3–6.2
Broken trunk-dead	4.3 ± 0.8	2.9–5.8	11.8 ± 2.0*	8.5–15.5
Uprooted	15.4 ± 4.1	7.3–21.1	25.7 ± 4.9*	17.0–34.1

* Statistically significant difference by Mann–Whitney test—SPSS, between HPH and IPPK at $p < 0.05$ p-value: 2* (1-tailed Sig)—not corrected for ties.

4 trees ha^{-1}, respectively) and 30–50 cm (8 trees ha^{-1} versus 3 trees ha^{-1}, respectively). IPPK harvests would also result in higher losses than HPH selective logging from the population of future harvest trees in logged-over forest (39 trees ha^{-1} versus 28 trees ha^{-1} (Fig. 3b), respectively). Significant differences were in diameter classes 10–30 cm (21 trees ha^{-1} versus 11 trees ha^{-1}, respectively) and 30–50 cm (11 trees ha^{-1} versus 7 trees ha^{-1}, respectively). However, HPH's subcontractor harvesting in primary forest resulted significantly higher losses than HPH logging staff in all diameter classes (23 trees ha^{-1} versus 9 trees ha^{-1}), with similarly losses were found when compared to IPPK (28 trees ha^{-1}). The difference was only found in diameter class 10–30 cm dbh (11 trees ha^{-1} versus 15 trees ha^{-1}, respectively).

Table 4
Trees damaged per 100 m length of skid trail or logging road (trees 100 m^{-1}) due to HPH and IPPK logging in logged-over forest

Types of damage/ locations	Skid trail + felling gap		Logging road	
	Mean ± S.E.	Range	Mean ± S.E.	Range
HPH (n = 6 plots)				
Bark and wood damage	1.4 ± 0.3	0.5–2.7	0.1 ± 0.0	0.0–0.1
Leaning	2.1 ± 0.4	1.1–3.0	0.4 ± 0.1	0.0–0.7
Crown injury	15.3 ± 1.5	10.4–19.8	11.3 ± 1.3	7.9–15.1
Broken trunk-alive	4.4 ± 0.6	2.7–6.7	4.5 ± 0.5	2.9–6.1
Broken trunk-dead	4.7 ± 0.5	2.6–5.6	4.6 ± 0.6	2.4–6.5
Uprooted	9.5 ± 1.1	5.0–13.7	5.3 ± 0.8*	2.8–8.0
IPPK (n = 15 plots)				
Bark and wood damage	1.3 ± 0.2	0.0–3.1	0.4 ± 0.1	0.0–1.2
Leaning	1.6 ± 0.2	0.0–2.9	1.2 ± 0.3	0.0–4.4
Crown injury	16.8 ± 1.2	8.4–22.2	17.2 ± 2.5	6.9–47.5
Broken trunk-alive	4.3 ± 0.3	2.7–6.1	5.2 ± 0.4	3.1–8.3
Broken trunk-dead	4.2 ± 0.3	2.3–6.5	7.5 ± 0.9	1.4–14.2
Uprooted	14.3 ± 1.6	6.1–27.2	15.0 ± 2.9*	1.6–38.7

* Statistically significant difference by Mann–Whitney test—SPSS, between HPH and IPPK at $p < 0.05$ p-value: 2* (1-tailed Sig)—not corrected for ties.

5. Discussion

5.1. Harvest intensity

Harvest intensities documented in this study (1–4 trees ha^{-1}) can be classified as "low" as compared to other selective logging studies in Borneo (5–15 stumps ha^{-1}, Bertault and Sist, 1997; 6–14 stumps ha^{-1}, Pinard et al., 2000a; 7–11 stumps ha^{-1}, Sist et al., 1998). Removals might be described as under-harvesting, as they are lower than permissible harvest levels, which range from 8 to 10 trees ha^{-1} depending on tree diameter and the annual allowable cut (AAC) calculated from inventories. Our low harvest estimates may reflect the different methodology used for our study as compared to others. Estimates in other studies were based on permanent sample plots ranging in size from 1 to 4 ha, which were established before logging operations (Suhartana and Idris, 1998; Pinard et al., 2000a; Sist et al., 2003). We used sample plots of 20 ha, established in areas previously harvested. We may have underestimated harvest levels, because we could not be sure that all stumps of harvested trees remained to be counted in cleared areas (i.e. log landings and logging roads). However, it may be that low levels of harvest by HPH logging crews in primary forest were deliberate, reflecting a recognized lack of machinery or resources for harvesting on the part of this state-owned company. It is not uncommon for low harvests by HPH logging crews to be followed by subsequent harvests, usually a few months later, by a HPH's subcontractor that is better equipped, to fulfil their AAC. Strictly speaking, this qualifies as repeat-entry harvesting, which is a violation of TPTI regulations.

The different stump size distribution and harvest intensities between HPH and IPPK logging may reflect differences in their respective markets for logs. A study by Obidzinski and Suramenggala (2000) in East Kalimantan revealed that many logs from IPPK harvests were sold to local sawmills. These mid-size and small sawmills process for local consumption smaller logs than those HPH logging operators send to plywood industries in East Kalimantan. The differences in stump size and harvesting intensities between IPPK and HPH logging may also reflect the fact that IPPK permits incorporate no exact harvesting guidelines, whereas HPH selective logging operators are required to follow TPTI guidelines, with their minimum diameter limits of 50 cm. However, considering the result from HPH's subcontractor, after the IPPK system was put in place, several HPH operations were operating like IPPK. These revealed from similarity in harvest intensity and damaged by their logging operations. FWI/GFW (2002) found that IPPK holders' permits, lacking guidelines, favour maximizing current harvests, including trees below the TPTI diameter limit. In the case of HPH selective logging, many of the stumps <50 cm were found along logging roads, where trees had been cut to clear land for road maintenance and building materials, rather than for timber.

5.2. Logging road and skid trail and length

Several authors have reported that at low harvest levels (<4 trees ha^{-1}) most logging damage results from road construction rather than the felling of trees (e.g. Gullison

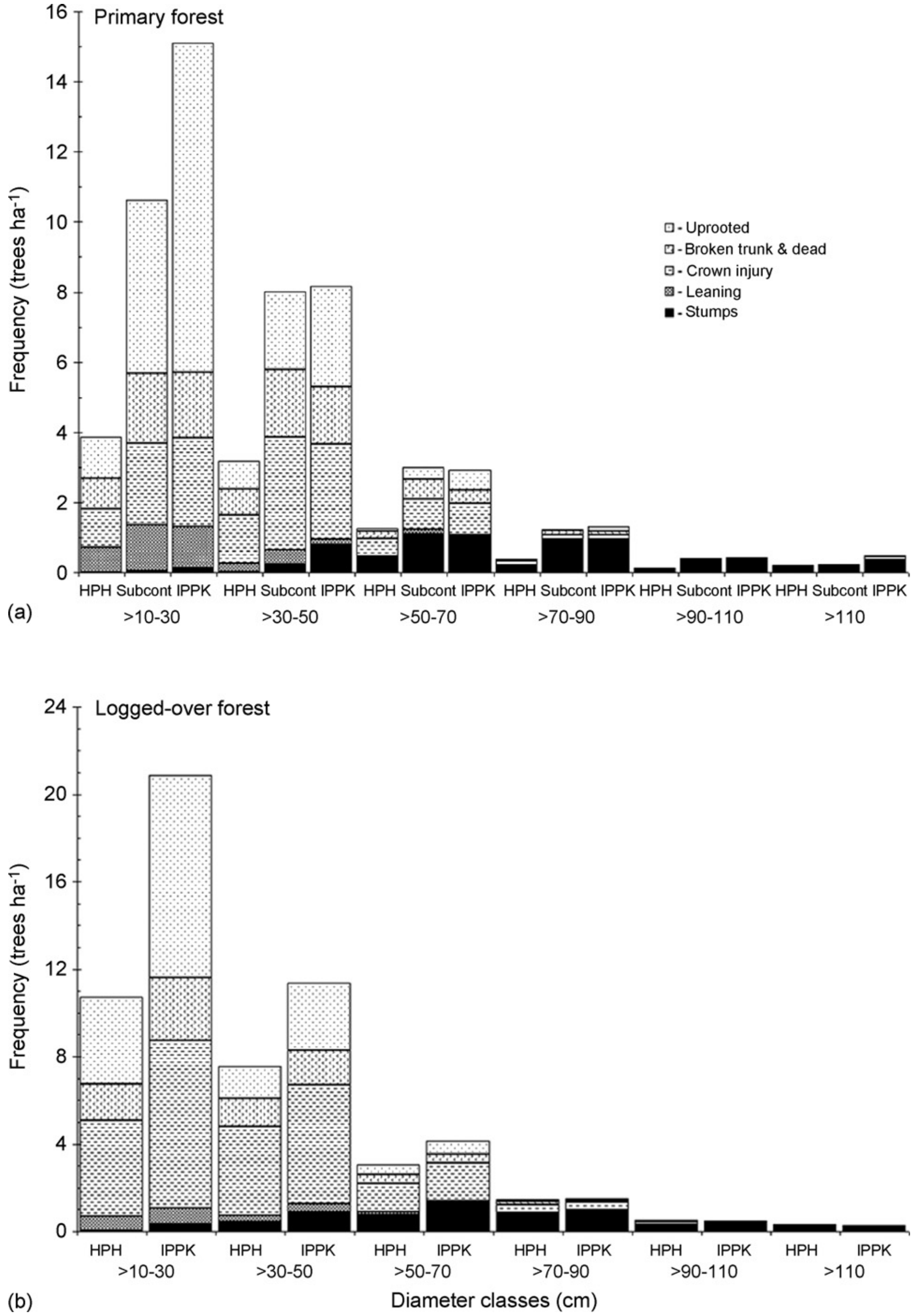

Fig. 3. Frequency and distribution of potential loss of trees (trees ha^{-1}) by logging concessionaires (HPH), HPH's Subcontractor, and short-term permit holders (IPPK) in both forest types.

and Hardner, 1993; Sist et al., 2003). Similarity between operators in road length per hectare reflected the fact that many IPPK harvesting operations were using logging roads that had been previously constructed by HPH. They also used the same type of machinery. This similarity in road length may also reflect the topography in the study area. A study by Johns et al. (1996) in Brazil reported that planned and unplanned logging operations in even topography constructed similar lengths of roads.

Logging road length per hectare in this study (from 25 to 34 m ha^{-1}) was relatively similar to those described by Johns et al. (1996) of 23 m ha^{-1} in a 105 ha to 27 m ha^{-1} in a 75 ha area, with harvest intensity 5 and 6 stems ha^{-1}, respectively. In a larger study area in Bolivia, Gullison and Hardner (1993) reported that 8 m ha^{-1} of roads were built resulted from harvest intensity 0.1 stems ha^{-1} within a 602 ha felling area. These differences may reflect the different methodology used for these studies, i.e. average of logging road length per ha declines as the sample area increases.

A reason for extensive skid trail length per hectare in IPPK and HPH's subcontractor logging in primary forest (49 and 52 m ha^{-1}, respectively), as well as IPPK logging in

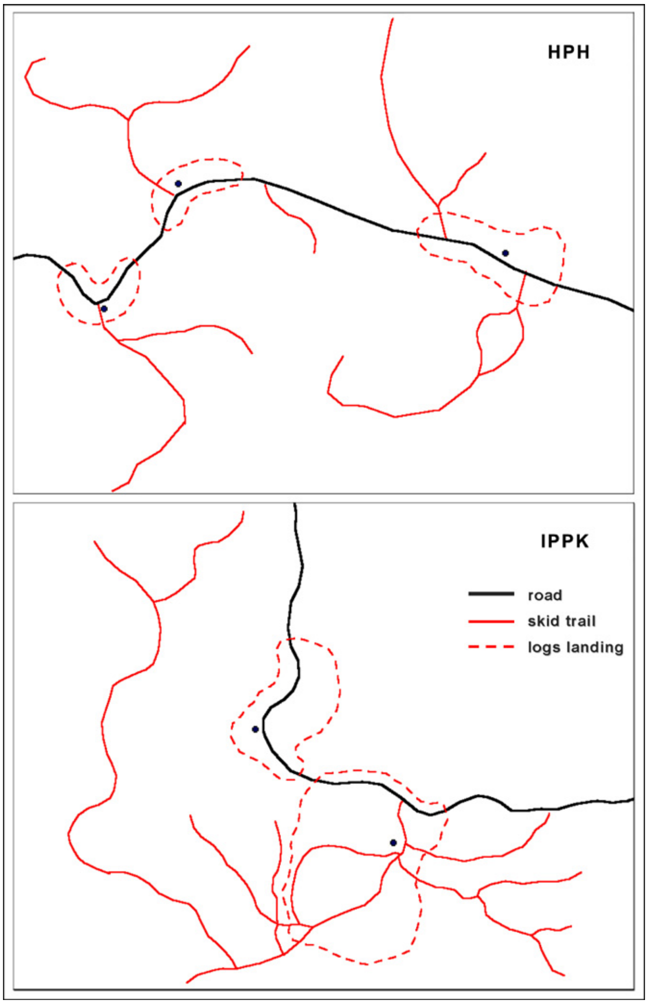

Fig. 4. Differences of road, skid trails, and log landings constructed in logged-over forest between concessionaires (HPH) and short-term permit holders (IPPK) logging operations.

logged-over forest (63 m ha^{-1}) were revealed by visual checks of those operators logging areas. The choice of where to create a skid trail was determined by the crawler tractor drivers trying to get access to areas where trees had been cut. This resulted in a network of unplanned skid trails to pull the logs from stumps to the log landing (Fig. 4). Many of these skid trails were not utilized for log transport but as short cuts to felling gaps, leading to many dead ends and turns that resulted in damage. It is widely acknowledged that the key to reducing impact and ground area disturbance is to reduce unnecessary skidding (Suhartana and Idris, 1998; Jackson et al., 2002).

Total length of skid trails and road length per number or volume of harvested trees was generally smaller for IPPK than HPH logging (except for skid trail length in logged-over forest). This reflected the higher number of trees harvested by IPPK and HPH's subcontractor, which reduced the length of skid trails and roads per unit harvested. With these facts, IPPK and HPH's subcontractor do better and more efficient in terms of machinery utilize for road and skid trail construction compared to HPH logging staff operations.

Skid trail lengths measured in our study (34–63 m ha^{-1} in a 20 ha plot) were much lower than those reported by Johns et al. (1996) from Brazil (158 m ha^{-1} in 105 ha plot to 171 m ha^{-1} in 75 ha with harvest intensity 5 and 6 stems ha^{-1}, respectively) and Whitman et al. (1997) in Belize (104 m ha^{-1} of skid trail with harvest intensity 0.5 stems ha^{-1} in 92 ha). Moreover, Pinard et al. (2000a) in Malaysia reported with higher harvest intensity of 14 stems ha^{-1} resulted in 168 m ha^{-1} of skid trails in 50-ha plot. However, in a larger study area in Bolivia, Gullison and Hardner (1993) reported 14 m ha^{-1} of skid trails resulted from harvest intensity 0.1 stems ha^{-1} in a 602-ha plot. These differences may reflect the different methodology used, and different harvest intensities among the studies. Average length of skid trails per ha is reduced as study areas increase and harvest intensity declines.

5.3. Logging damage to residual trees

The direct impact of logging on forests is obviously a net reduction in trees. However, the indirect impacts from damage, mortality, and rot to residual trees also affect the future health of forests (Pinard and Putz, 1996). Logging activities by IPPK permit holders resulted in higher numbers of damaged trees per hectare than logging by HPH in both forest types. In primary forest, the higher number of trees >90 cm dbh harvested by IPPK and HPH's subcontractor would be expected to have affected the size of canopy openings and the number of damaged trees. Other studies in Kalimantan suggested that felling intensity was an important feature in the damage caused by logging (Bertault and Sist, 1997; Sist et al., 1998). In logged-over forest, the differences in damage between the two types of operators reflected better harvesting techniques on the part of the private HPH logging operator. IPPK permit holders harvests resulted in excessive skid trail networks and log landings. However, the high levels of harvest by IPPK reduced the incidence of damage per unit and volume (m^3) of trees harvested, compared to HPH.

Overall, IPPK permit holders operations resulted in a higher number of damaged trees per 100 m-unit length compared to HPH logging. The number of trees damaged per 100 m length of skid trail and road (from 20 to 43 trees 100 m^{-1}, Table 2) was much lower in this study as compared to the study by Johns et al. (1996), which documented revealed 67–135 damaged trees 100 m^{-1} length in planned and unplanned logging areas, respectively. However, our results were similar to those reported by Jackson et al. (2002) in Bolivia (42–56 trees 100 m^{-1} road length). These differences probably reflected higher levels of harvests (6 stems ha^{-1}, Johns et al., 1996) compared to those in our study, which ranged from 1 to 4 stems ha^{-1}. Most damaged trees were in diameter classes 10–30 cm, paralleling observations by Sist et al. (2003) in East Kalimantan that the highest number of damaged trees were in diameter classes 20–30 and 10–40 cm dbh resulted from observation by Pinard and Putz (1996) in Malaysia.

Total canopy opening per hectare, ranging from 1106 to 3226 m^2 ha^{-1} (Table 2A) was relatively similar to rates reported in other studies of conventional logging (2276 m^2 ha^{-1}, Johns et al., 1996; 2575 m^2 ha^{-1}, Jackson et al., 2002). Study by Pinard et al. (2000a) in Malaysia, reported with harvest intensity of 14–11 stems ha^{-1} resulted in 1660–1020 m^2 ha^{-1} of canopy opening in conventional logging areas of 50 and 70 ha, respectively. In Brazil, Pereira et al., 2002 found at a harvest intensity of 6 trees ha^{-1}, conventional logging operations in 14-ha area produced 1120 m^2 ha^{-1} of canopy openings, whereas in 112-ha area with harvest intensity of 4 trees ha^{-1} resulted in 890 m^2 ha^{-1} of canopy openings.

The high levels of harvest by IPPK and HPH's subcontractor reduced the incidence of logging damage per number and volume of trees harvested compared to HPH logging staff. The number of trees damaged and total canopy opening were found not significantly difference between operators in both forest types. These reflected that harvest intensity would have affected damaged by logging, which reduced the degree of disturbance from logging operation per hectare or unit area. With all detail of harvesting practices gathered, IPPK and HPH's subcontractor certainly do better and more efficient harvesting operations compared to HPH logging staff operations, due to its ''low'' damage. However, for the purpose of sustainability-managed timber harvesting in long-term basis and the future health of forests, logging practices by these operators were classified as a low-grade system.

Large canopy openings can promote the regeneration of pioneer species, and may limit the establishment of Dipterocarp regeneration due to competition (Pinard et al., 2000b). However, several authors have reported that regeneration and growth of commercial trees tended to be greater in the most severely damaged stands more than a year after canopy opening creation (Sist and Nguyen-The, 2001; Fredericksen and Pariona, 2002). Observations in logged-over forest areas in East Kalimantan show that many Dipterocarp species (*Shorea laevis*, *Shorea leprosula*, *Shorea parvifolia*, and *Dryobalanops aromatica*) regenerate on skid trails, in felling gaps, and along logging roads (Kartawinata, personal communication).

5.4. Category of damage to residual trees

In both forest types, significant differences between operators in types of trees damage were found only for uprooted trees along logging roads. This reflects the higher number of smashed trees that had been pushed by the crawler tractor to the roadside during road construction on short-term permit holder areas. Many of these uprooted trees were in small diameter (<30 cm) or lower value timber species, which encouraged the crawler tractor drivers to clear them. Another reason is that when the temporary log landings were full, logs were piled along the roads, damaging smaller trees along the edges.

Trees with crown injury and broken trunk-dead dominated the damage category along logging roads in both forest types. Most were in small diameter classes (<50 cm), which reflects the higher level of secondary damage to residual trees during road construction. Secondary damage due to road construction is typically greater than secondary damage caused by the felling of commercial trees (Gullison and Hardner, 1993). Trees pushed over fall into adjoining forest, injuring more trees and creating a corridor of damage considerably wider than the road itself. Although the length of logging road per plot was lower than skid trail length, there was substantially more damage to the forest along roads.

This study quantified the total number of harvested and damaged trees, but we did not collect data on the number or species of remaining, undamaged trees. Another study in this area recorded the density of 210 trees ha^{-1} < 50cm dbh (Sist et al., 2003). This would mean that the rates of damage we recorded, which ranged from 18 to 32 trees ha^{-1} < 50 cm dbh (in both forest types) would correspond 9–15% of pre-harvest tree density. These estimates are lower than those described by Pinard and Putz (1996), which ranged from 17 to 57%; and Sist et al. (2003) that ranged from 19 to 56% of initial tree density. The difference may reflect the different methodology used as well as the different harvest intensity in our study.

It is hard to know whether levels of damage of 9–15% of pre-harvest trees <50 cm would have a significant impact on the future harvest potential of these stands. Furthermore, Pinard and Putz (1996) found that 10–43% of trees with moderate types of damage (stem, bark damage) and trees snapped-off in diameter classes <60 cm died during the first year after logging.

Other studies have reported that mean annual mortality rate in logged-over forest during the 2 years following logging operations was 2.6% per year, reflecting higher mortality of trees damaged during logging (4.9%); which declined in year 4 after logging to 1.5% per year (Sist and Nguyen-The, 2001). This suggests that between now and the time of the next polyclic harvest, in 35 years, the number of dead resulting from mortality of damaged trees documented in this study would be low compared to the number of dead trees that would result from average annual mortality rate. In other study, Bertault and Sist (1997) found that 23% of pre-harvest trees (115 trees ha^{-1}) died during conventional logging operations.

6. Conclusion

Although IPPK and HPH's subcontractor certainly do better and more efficient harvesting operations, in terms of total number and volume of trees harvested. However, these practices were classified as a low-grade system for the purpose of sustainability-managed timber harvesting and the future health of forests. This high levels of harvest combined with large numbers of damaged trees by IPPK and HPH's subcontractor implies that future harvest options will be lower and reduces future timber potential harvest in these areas. Increases in total canopy openings beyond natural conditions in unplanned logging by IPPK and HPH operations may favour regeneration of pioneer trees and limit the natural establishment and growth of dipterocarp species due to competition. However, the long-term density of trees growing on areas with high levels of disturbance during logging remains uncertain (Pinard et al., 2000b).

This suggests that the lack of long-term license guarantees and a near-complete lack of government regulation encourages higher harvest and harvest-related damage rates. However, without proper harvesting regulations and supported by the well-established control institution, harvesting practices under

HPH system resulted in similar logging damage to harvesting under IPPK system.

Both types of operators could reduce damage to the soil and residual trees, which may contribute to the sustainability of timber harvesting in the future for both community and district government by: (1) switching from the use of heavy and destructive crawler tractor to lighter and more environmentally friendly machinery; (2) following reduced impact harvesting practices. Previous studies in Kalimantan have quantified the difference in networks of skid trails constructed with different machinery (Klassen, personal communication; Sist et al., 2003). Skidding with lighter and smaller machinery like the pulldozer tractor CAT 527, with narrow blades (3 m wide) and enhanced maneuverability resulted in lower total skid trail length and impact to the soil than skidding with CAT D7G crawler tractor.

Acknowledgements

Special thanks goes to those who have provided their invaluable contributions to this research, namely: Dr. Machfudh of CIFOR/FORDA for his assistance and comments in preparing the proposal and preliminary data, Anton Hidayat from BIOMA and Dyfrig F. Hubble of CIFOR, for their great assistance in data collection during the field work. Meilanie and Ramadhani Achdiawan for their inputs in data analyses. We are very grateful to PT. Inhutani II unit Malinau, PT. Intracawood Mfg., and Malinau District Government for providing us with the opportunity and assistance to work on Malinau forest. The Government of Japan and The U.S. Agency for International Development (USAID) funded this study.

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