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Application of Conventional and Improved Techniques in Felling and Skidding to Residual Stand Damages

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Abstract

Felling and skidding are essential in the timber extraction process. But on the other hand, residual stand damage can't be avoided. This study aimed to analyze the impact of conventional and improved felling and skidding techniques on residual stands in natural forests. Three observation plots were developed to identify the types, numbers, and criteria of residual stand damage due to both techniques. The criteria were categorized as a) minor damage (<25%), b) moderate damage (25–50%), and c) major damage (>50%). It showed that the conventional felling and skidding techniques caused damages of 14.92% dominated by tree crown damage and 16.70% dominated by stem wounds, respectively. The residual stand damage due to conventional felling and skidding techniques was 31.62% categorized as medium damage. Meanwhile, improved felling and skidding techniques caused damage of 9.89% dominated by broken trees and 10.27% dominated by stem wounds, respectively. The residual stand damage due to improved felling and skidding technique was 20.16% categorized as minor damage. The improvement techniques can minimize residual stand damage by 36.24%. Therefore, a good understanding of forest concessionaires regarding RIL principles is necessary for achieving sustainable timber harvesting

Keywords: *felling, natural forest, residual stand damage, skidding*

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Introduction

Felling and skidding are crucial parts of timber harvesting activities. These activities could harm the natural forests' sustainability, including the residual stand damages. Damage to the residual stands occurred due to the felling and skidding activity (Matangaran et al., 2019). As a result of felling, it causes damage to the trunk, especially the tree canopy, and skidding causes death to stand in the skidded area.

The use of harvesting machines, particularly during timber skidding activities, has a serious impact on forests. Some studies showed that the utilization of heavy machines in Indonesia's forest skidding has improved soil compaction (Matangaran, 2012; Matangaran & Suwarna, 2012; Muhdi, 2016). This change in soil property affects the seedling and existing stand growth capability (Matangaran et al., 2006; Matangaran & Suwarna, 2012). Furthermore, (Budiaman et al., 2020) reported that soil compaction due to tractor-logging affects the abundance of ground ants, which has an important role in determining soil fertility. Therefore, the impact assessment of harvesting machines on the forest ecosystem was necessary to develop a feasible harvesting system since the mechanized harvesting operations have a long-lasting effect on the residual stand in the forest (Badraghi et al., 2015).

Operations in the forest could also pose risks to forestry workers; in fact, they are more vulnerable compared to nature itself. Forestry workers could experience occupational safety and health disturbances. According to Yovi et al. (2012) and Yovi and Amanda (2020), this is caused by several factors, namely: 1) having low education, which is the existence of a gap in each of the competency elements on knowledge, skill, and attitude between the worker's perception and the work practice standard. Both supervisors and workers tend to overestimate their knowledge, skill, and attitude level; 2) outsourcing workers; 3) are paid under quantity done. The wages are paid based on the volume. However, this payment system may drive workers to pursue higher production; 4) consuming less nutritious food; 5) as their main livelihood.

The condition of the residual stands will affect further forest management activity. According to Daniel et al. (1979), the residual stands of commercial species such as *Shorea* spp. in all tree growth levels seedlings: high up to 1.5 m, saplings: high > 1.5 m and diameter <10 cm, poles: diameter of 10 to < 20 cm, and small trees: diameter > 20 cm) potentially become harvested trees for the next rotation. It was reported that the damage to the residual stand could reduce future tree growth and stand value (Hwang et al., 2018). Residual stand damage also generates the loss of one or more areas covered thus the area exposed. Changes in growing conditions due to timber harvesting activities such as soil compaction and canopy exposure led to the aggressive growth of pioneer species. This will hamper the growth of

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commercial stands since their growth increment is not achieved optimally. Pioneer species are generally included in the non-commercial species group, are characteristic of logged-over forests and generally have fast growth (Venturoli et al., 2015). Therefore, high damage to the residual stands can reduce wood production in the next felling rotation.

Several types of damage occurred to the residual stands around the felled trees. It was a damaged crown, damaged bark, broken stems, tilted, collapsed, and damaged buttresses (Elias, 2008). Those damages were caused by a hit from the felled tree, either by its crown, branch, or trunk during the tree felling. The types of tree damage will affect the stands' growth. Some studies showed that the damage to residual stands, such as rot and death, affects the growth of the stands (Guyon, 2017). Felling and skidding activities in Indonesia's natural forests have not fully considered production and environmental sustainability. Whereas, the amount of forest products obtained from timber harvesting activities is one of the indicators used to assess the socio-economic and environmental effects of natural forest management (Vidal et al., 2016). In particular, the restoration of timber volumes is one of the main determinants of forest management. Fantini and Siminski (2016) estimated the volume of harvestable wood in secondary Atlantic forests to be 36 million m^3. If reduced impact logging (RIL) is properly applied, it can increase the sustainability of timber yields by reducing stand damage and can increase the rate of post-harvest logging stock recovery (Roopsind et al., 2018).

PT Eksploitasi dan Industri Hutan (PT Inhutani I) Sambarata Unit, East Kalimantan, is a natural forest concession that existed as a state-owned forestry holding company. PT Inhutani I Sambarata Unit has implemented the sustainable production forest management (*pengelolaan hutan produksi lestari*, PHPL) system since 2012. This was proven by the issuance of Minister of Forestry Decrees P. 45/Menhut-II/2012 and P. 8/VI-BPPHH/2012 with a good rating concerning criteria and indicators for sustainable production of natural forest management in management units. However, when this study was conducted, PT Inhutani I still applied a common timber harvesting technique used by other local companies (which was later considered a conventional technique in this paper). The company surrenders all the timber harvesting activities to the harvesting contractor. Meanwhile, currently, RIL (which was later considered an improved technique in this paper) has the potential to improve logging efficiency while reducing residual stand damage and carbon emissions compared to conventional logging (Dulsalam et al., 2021). Therefore, this study aimed to analyze the impact of conventional and improved felling and skidding techniques practiced on residual stand damage in natural forest concessions.

Methods

Study area The research was conducted in the natural forest area concession of PT Inhutani I Sambarata Unit, logging compartment number 339, Berau District, East Kalimantan (Figure 1). Geographically, PT Inhutani I Sambarata Unit is located between N0215′15″–E11700′09″ and N0240′21″–E11729′25″. According to a company report on timber cruising, PT Inhutani I Sambarata Unit managed a total area of 106,020 ha. Furthermore, the company managed a working area of 2,934.58 ha which has a total commercial trees reached 116,015 trees or a total volume of approximately 240,284.85 m^3. The land slope of the study area varied from rather steep (15–25%) to steep (25–45%) (Decree of the Indonesia Minister of Agriculture Number 837/Kpts/Um/11/1980). The condition of the average slope of the land configuration is rather steep, and some of the land is also steep.

Skid trails are roads that connect one tree to a landing point. The skidding trails were constructed to connect one tree fell. The construction of skid trails was carried out simultaneously with the extraction of logs after the trees fell.

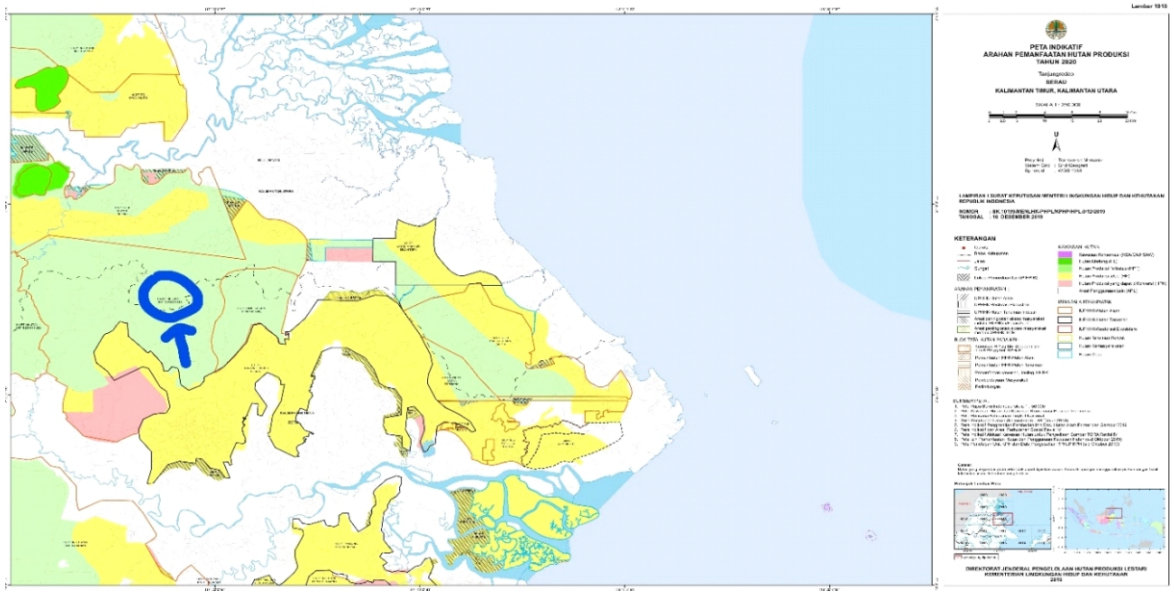

Figure 1 Location of study site in PT Inhutani I Sambarata Unit, Berau District, East Kalimantan.

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The length and width of the skid trail depend on the position of the trees being skidded to the landing point. The average length and width of the skid trails are 114 m and 6.4 m, respectively.

The materials used in this study were tally sheets and a tree map. Then, the equipment used was chainsaws, skidders, global positioning systems (GPS), compasses, and computers.

Data collecting On the selected logging compartment, three observation sample plots were developed with the size of 2.0 ha (200 m × 100 m). Plots were designed by systematic sampling with a purposive start. This sampling employed purposive sampling for the first plot. The first plot was purposely selected on the logging compartment, and the next plots were systematically developed with a distance between plots of 100 m (Figure 2). The criterion of the first plot in this sampling was an even distribution of the number of stands to be felled to accommodate the sampling tree number. The stand distribution was captured based on the company's annual work plan (*rencana kerja tahunan*, RKT), particularly on the timber cruising report (*laporan hasil cruising*, LHC) and stand inventory before logging (*inventarisasi tegakan sebelum penebangan*, ITSP). There, the first plot was considered from those reports. These plots were developed according to the map of the timber harvesting operational plan at a scale of 1:50,000.

Thereafter, a standing inventory before logging was conducted for all tree species with a diameter at breast height (dbh) of ≥ 20 cm. This inventory also recorded the number of felled trees. Then, after logging was performed, an inventory of the residual stands was conducted. This inventory recorded the number of damaged trees and their damage types. Those procedures were replicated for the recording of damage from skidding activities and were supplemented by recording the number of trees skidded.

Observation of residual stand damage by counting the number of the residual stand damaged and types of damage (crown damage, broken stem, collapsed, tilted, stem wounds, buttress wounds, and root wounds) These damage types were determined by directly observing the type or form of damage to the residual standing after a tree was felled or skidded. According to Decree of the Director General of Forest Exploitation Number 564/KPTS/IV-BPHH/1989 concerning guidelines for selected felling and Indonesian planting (TPTI), a stand was categorized as damaged if it experienced one or more of the following conditions: a) the tree crown was categorized as damaged if > 30% of the tree branches/main branch were broken; b) stem wound reached wood measuring more than 1/4 of the circumference of the trunk with a length of more than 1.5 m; and c) rootswere cut or 1/3 buttresses were damaged.

Felling and skidding were performed by applying conventional and improved techniques to the sampling plots. In this study, the conventional technique is the existing timber harvesting technique that is applied by the company. This technique is commonly used by other local forest concessions and completely surrenders the timber harvesting activities to the harvesting contractors. Meanwhile, the improved technique is the timber harvesting technique, that follows the correct harvesting and RIL principles. The improved technique was directed by the researchers during the timber harvesting activities. Table 1 elaborates on the differences between conventional and improved techniques found in the field according to researchers' observations.

Timber felling activity in this study was conducted by a chainsaw operator who has three years of experience in natural forest timber logging. Previously, the operator

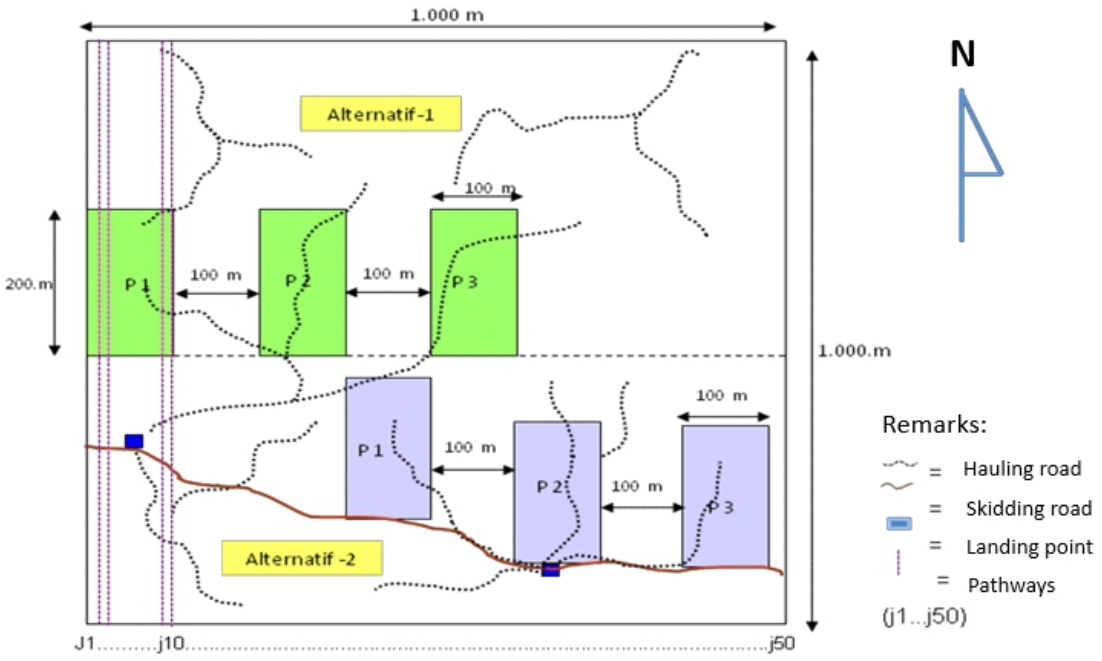

Figure 2 Design of observation sample plots in the logging compartment (Soenarno et al., 2017).

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worked as a chainsaw operator in oil palm plantations. This operator also never attended RIL training. The chainsaw operator was assisted by a helper during the logging activity. Likewise, the skidding activity was also conducted by a skidder operator and assisted by a helper.

Data analysis The residual stand damages due to felling and skidding activities were calculated using the formula as shown in Equation *[1]* (Elias, 1998).

$$K = \frac{R}{P-Q} \times 100\% \qquad [1]$$

note: K = percentage of residual stand damage; R = number of trees with a diameter of ≥ 20 cm that were damaged according to their damage types; P = number of trees with a diameter of ≥ 20 cm before felling; and Q = number of trees felled. The criteria for residual stand damage based on the percentage of residual stand damage are: 1) minor damage: if the damage is < 25%, 2) moderate damage if the damage is between 25–50%, and 3) major damage if the damage is > 50% (Elias, 1998).

Results and Discussion

Residual stand damage due to felling The residual stand damage due to conventional felling is presented in Table 2. It shows that the conventional felling technique with 10 felled trees affected 12 damaged trees. It may be influenced by the area's topography, which is dominated by sloping land, so chainsaw operators face difficulties. Therefore, the land slope should not become an issue if the saw operators have qualified skills. According to (Muhdi et al., 2020) the skill aspect has a relationship with the attitude aspect, so to improve aspects one will improve the other aspects as well. The results of research by (Yovi et al., 2016) show that all respondents overrated their OSH knowledge reflecting serious problems in the field of OSH in the forestry work in Indonesia.

The damage type of residual stand was dominated by crown damage and broken stems, with 4 trees for each. Other studies on Indonesia's tropical forests also showed similar damages suffered by the residual stands. (Soenarno et al., 2017) reported that broken stem was the dominant damage type (56.37%) that occurred due to felling activity in a tropical natural forest of Central Kalimantan. Furthermore, (Matangaran et al., 2019) reported that broken stem and crown injuries were the dominant damage types that occurred due to logging in the tropical forests of Central Kalimantan and West Sumatra. The broken stem suffered by the residual stand after conventional tree felling is captured in Figure 3. Further, Table 3 shows the improved felling technique has the average residual stand of 10 trees damaged which dominated by broken stem damage type. These damages occur when a felled tree falls into the surrounding stands, affecting the loss or damage of tree crowns and stems.

In this study, the average residual stand damage due to the conventional felling technique was 14.92% which was categorized as minor damage (Table 2). Furthermore, the residual stand damage due to improved felling technique was 9.89% and categorized as minor damage (Table 3). These damage rates are lower compared to other studies in several forest types across regions. (Soenarno et al., 2017) reported that the damage rate due to felling in the tropical forest of Central Kalimantan reached 16.27%. (Matangaran et al., 2019) also reported that the damage rates identified in Central Kalimantan reached 27.8% and West Sumatra reached 22.4 Meanwhile, Dudáková et al. (2020) reported that the damage percentage to residual stands in Slovakian forests amounted to 20.47% and 23.36%.

Table 1 Design of observation sample plots in the logging compartment (Soenarno et al 2017).

Working elements	Improved technique	Conventional technique
Felling	• The tree felling direction not only considers the wind direction but also the skidding trail direction • The maintenance of felling tools (chainsaws) should be performed periodically	• The tree felling direction was only determined according to the wind direction • The lack of felling tools (chainsaws) maintenance conduce obstruction to tree felling activities since the tools were damaged
Skidding	• The skidding trails should be planned and constructed before trees fall • The skidding operator should be equipped with a tree map as guidance during timber skidding	• The skidding trails were constructed after trees fell • The skidding operator was not equipped with a tree map affecting the tractor maneuver a lot (did a zig-zag move).

Table 2 Residual stand damage due to conventional felling techniques

Plot number	Number of trees with a diameter ≥ 20 cm		Number of felled trees	Type of damage				Total	Residual stand damage
				Crown	Broken stem	Steam wounds	Collapsed/ tilted		
	(tree ha^{-1})	(tree)	(tree)	(tree)	(tree)	(tree)	(tree)	(tree)	(%)
1	54	86	10	2	7	3	2	14	18.42
2	49	105	8	6	0	4	1	11	11.34
3	47	92	12	3	4	3	2	12	15.00
Average	50	94	10	4	4	3	2	12	14.92

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Table 3 Residual stand damage due to improved felling techniques

Plot number	Number of trees with a diameter ≥ 20 cm		Number of felled trees	Type of damage					Residual stand damage
				Crown	Broken stem	Steam wounds	Collapsed/ tilted	Total	
	(tree ha^{-1})	(tree)	(tree)	(tree)	(tree)	(tree)	(tree)	(tree)	(%)
1	66	88	7	3	4	3	1	11	13.58
2	58	110	13	1	2	2	1	6	6.19
3	60	95	10	2	3	2	2	9	10.59
Average	61	98	10	2	3	2	1	9	9.89

Figure 3 Residual stands damaged due to felling.

The average residual stand damage with the improved technique was lower (9.89%) compared to conventional techniques (14.92%). There, it can minimize the residual stand damage by 33.71% since applying the improved technique. The improved technique is a timber harvesting technique that follows the proper and correct RIL principles, such as how to make under the cut, backcuts, the felling direction of trees, etc. Elias et al. (2001) stated that the best procedure for determining the felling direction was to approach or avoid the skid trail by forming an angle of 30–45 (fish fin pattern) or the felling direction in a parallel position on the skid trail with the opposite direction to the skid trail if allows the felling directed to a clear area and to the canopy of the tree that was previously felled (maximum of 3) and on steep areas the felling direction was oblique to the side of the slope (along the contour). The residual stand damage caused by felling could be avoided and minimized so that stand growth for the following year and product quality could increase (Bodaghi et al., 2020).

The field observations showed that chainsaw operators did not understand how to determine the proper and well-planned tree-felling direction. Many of the trees were directed toward ravines and areas with dense residual stands. The type and amount of residual stand damage that occurred during timber harvesting depend on the number of trees, stand density, felling intensity, tree diameter, crown size, felling direction, harvesting technique, and operator skills. Danilović et al. (2015) stated that the amount of residual stand damage would increase as the tree diameter increased. Further, another study showed that the highest frequency of damage was observed on trees with a diameter at the breast height class of 20 cm (24.3%) (Nikooy et al., 2020). Nikooy et al. (2020) also reported that most of the stand damage occurred on the bole (55%) of trees, with wound sizes ranging from 50–350 cm^2, and most of the wounds (53%) showed damage to the cambium and wood fibers at heights of <1 m above the ground line (76%).

Residual stand damage due to skidding Skidding is an activity to move logs from the logging compartment to the landing point. A recapitulation of the residual stand damage due to skidding using a conventional technique is presented in Table 4. Figure 4 shows the skidding activity and the tilted residual stand that was damaged due to skidding. The table shows that the timber skidding using conventional techniques caused damage to 14 trees (16.70%) and was dominated by stem wound damage (8 trees). Meanwhile, (Soenarno et al., 2017) reported that tilted/collapsed tree was the most common damage (67.8%) found due to skidding in the tropical forest of Central Kalimantan.

Stem wounds that occurred during skidding were due to the lack of skidding trail construction. This implies a lot of skidder maneuvering, which was performed by the operator during felled tree finding. Danilović et al. (2015) also stated that the level of residual stand damage during skidding was influenced by the direction of the skid trails. Therefore, the

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Table 4 Residual stand damage due to conventional skidding techniques

Plot number	Number of trees with a diameter ≥ 20 cm	Number of trees skidded	Type of damage			Total	Residual stand damage
			Buttress wounds	Stem wounds	Collapsed/ tilted		
	(tree)	(tree)	(tree)	(tree)	(tree)	(tree)	(%)
1	86	10	1	10	5	16	21.05
2	105	8	2	5	3	10	10.31
3	92	12	1	9	5	15	18.75
Average	94	10	1	8	4	14	16.70

Figure 4 Skidding activity in the logging area and tilted damage on the residual stand due to timber skidding.

skid trail direction should be traceable on the felled tree map to avoid high damage. The skidder operators need to provide a tree map to facilitate the felled tree tracking. A tree map contains the location and identity of the tree being felled.

Timber skidding using the improved technique resulted in lower residual stand damage compared to conventional techniques by 10.27% (Table 5). The timber skidding with improved technique can reduce the damage to residual stands by 38.50%. This technique follows the proper RIL principles and is thoroughly applied in the field; namely, the skidder operator carries a tree map so that the skidder operator does not perform excessive maneuvers, particularly in the gentle slope.

Apart from the direction of the skid trails, there is a natural factor that influences the residual stand damage, namely the forest stand density. The higher the forest stand density, the higher the potential for damage caused. (Matangaran et al., 2019) reported that the damage on the residual stand due to timber skidding was dependent on the density of forest stands. The dense stand conditions hamper the skidder's maneuvering when finding the logs, particularly if the skidding trails have not been built yet.

Residual stand damage due to felling and skidding Table 6 summarizes the percentage of residual stand damage due to felling and skidding according to Table 2, Table 3, Table 4, and Table 5. It shows that the percentage of residual stand damage due to felling and skidding of conventional techniques is 31.62%, which is categorized as "moderate" damage (damage between 25–50%). This shows that the timber harvesting activities conducted by the company have not implemented the improved technique.

The results of this study had an average percentage of stand damage lower than the results of another. In this study, the damage type was dominated by stem wounds. It was explained that the recovery speed of stem wounds depends on the length and width of the wound and the diameter of the tree. The wider the stem wound, the longer the healing process will take, so that the diameter growth will decrease by about 1.71%. Furthermore, stem wounds cause a decrease in tree diameter growth. The study by Khai et al. (2020) shows that five years after timber harvesting under Myanmar's selection system, the tree volume has decreased by 46% from 121 m^3 ha^{-1} to 65.1 m^3 ha^{-1}.

Table 5 also shows that the application of improved felling and skidding techniques leads to lower standing damage than conventional techniques, 20.16%, categorized as minor damage. The improved technique in this study was able to reduce the occurrence of residual stand damage by a percentage of 36.24%. Table 2 to Table 5 show that the conventional felling and skidding technique had an average stand of 94 trees, then caused damage to 26 trees after the harvesting, so the undisturbed residual stand was 68 trees. Meanwhile, the improved technique had an average of 98 stands before harvesting, then caused damage to 18 trees, so the undisturbed residual stands reached 80 trees. The damage percentage reduction of the improved technique is high. This means that if the implementation of the improved technique is feasible for natural forest harvesting, then sustainable production can be achieved.

The application of harvesting techniques used in timber harvesting activities also affects the damage level of residual stands. Kufre's (2018) study showed that the application of RIL could reduce residual stand damage by 20–50%. Meanwhile, the application of the Indonesian selective cutting and planting silvicultural system in natural forest concessions affects damage to seedlings (11.28%), saplings (11.56%), and poles (12.14%) which is categorized as

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Table 5 Residual stand damage due to improved skidding techniques

Plot number	Number of trees with a diameter ≥ 20 cm	Number of trees skidded	Type of damage			Total	Residual stand damage
			Buttress wounds	Stem wounds	Collapsed/ Tilted		
	(tree)	(tree)	(tree)	(tree)	(tree)	(tree)	(%)
1	88	7	1	6	4	11	13.58
2	110	13	2	4	3	9	9.28
3	95	10	2	2	3	7	8.24
Average	98	10	2	4	3	9	10.27

Table 6 Residual stand damage due to improved skidding techniques

Activity	Type of damage	Number of trees damaged (tree)		Percentage of damage (%)	
		Conventional	Improved	Conventional	Improved
Felling	Crown	4	2	14.92	9.89
	Broken stem	4	3		
	Stem wounds	3	2		
	Collapsed/tilted	2	1		
Skidding	Buttress wounds	2	2	16.70	10.27
	Stem wounds	8	4		
	Collapsed/tilted	4	3		

medium, while tree damage is categorized as low (9.9%) (Wahyudi et al., 2020). Furthermore, Purwoko et al. (2018) reported that the average residual stand damage for poles and trees per hectare due to reduced impact timber harvesting/RITH (19.53%) was lower than conventional (33.15%). These damages were categorized as moderate damage for conventional timber harvesting (25–50%) and minor damage for RITH (< 25%).

The implementation of RIL in the field should be precise and directed with close supervision from the foreman. Field observations indicate that chainsaw and skidder operators work on their experience, which leads to incompatible performance compared to RIL principles. de Avila et al. (2017) stated that sustainable forest management for timber production demands that the function of the forest be maintained and tree growth restored during the cutting cycle for sustainable production.

Conclusion

Felling and skidding are activities that play an important role in timber production, but these activities cannot be separated from the residual stand damage. In conventional felling techniques, crown damage and broken were the dominant types of damage, while stem wounds became common damage types. In conventional and improved skidding techniques, the dominant damage was stem wounds. Broken stems and stem wounds dominated the damage on improved felling and skidding techniques. The occurrence of residual stand damage can be reduced by 36.24% by applying improved techniques to timber harvesting. Therefore, this study recommends that natural forest concessionaires should have a good understanding of the application of RIL principles in the field to achieve sustainable timber production. The government could contribute to strengthening laws and regulations related to forest damage, particularly in production forests, and providing penalties.

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