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Research Article

Potential of Wood Harvesting Residues and Residual Stand Damage due to Timber Harvesting: A Case Study at PT Austral Byna in Central Kalimantan, Indonesia

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The practice of timber harvesting in natural forests which has been conducted up to now still leaves wood harvesting residue and residual stand damage. Most condition of wood harvesting residue is still good and can be utilized. The objective of this research was to determine the potency of wood harvesting residue and residual stand damage on timber harvesting in natural forests. The data on wood utilization, wood harvesting residue, and residual damage were collected from three sample plots. The sample plots were arranged in a systematic and purposive manner, and the data were processed with tabulation and average analysis. Research results showed that the average volume of wood being utilized was 9.212 m^3 $tree^{-1}$. The average volume of wood harvesting residues was 2.310 m^3 $tree^{-1}$, and the total average volume of wood harvesting residues which were good, defected, and broken was 2.121 m^3 (80.952%), with an average volume for good wood harvesting residue condition of 1.038 m^3 (34.808%). Proportions of wood harvesting residues were 2.154 m^3 (94.444%) consisting of buttress as large as 0.102 m^3 (5.159%), stumps as large as 0.375 m^3 $tree^{-1}$ (23.597%), butt as large as 0.855 m^3 (35.930%), and end part as large as 0.821 m^3 (29.758%). The average number of trees with a diameter of 20 cm which were damaged due to felling and skidding was 5 trees ha^{-1} (5.40%) and 6 trees ha^{-1} (6.58%), respectively.

1. Introduction

Over 60 percent of the world's round wood production originates from just eight sources: Brazil, Canada, China, the EU, India, Indonesia, Russia, and the United States. About half of this is accounted for by wood fuel and half by industrial round wood [1]. As one of the dominant natural forest harvesting practices, selective logging contributes about 15% of the global timber needs. Therefore, it is of global concern to ensure the sustainability of global forest benefits [2]. Harvesting includes the felling of trees, followed by crosscutting the felled trees into sections by a chainsaw operator. This is followed by manual debarking and stacking in preparation for transport [3]. Major factors affecting felling and processing productivities were tree volume and the number and thickness of branches for delimbing productivity [4].

Timber harvesting has a significant effect on forest environment. Wood harvesting differs radically from the harvesting of other crops. In that, logging can only be done by professionals who have received technical training on tree felling with careful, knowledgeable planning to minimize negative effects on the surrounding environment and on the residual stands [5]. There is room for improvement in the manual felling operation to improve upon the industry suggestion in the question to pay more attention to the felling process [6].

Wood harvesting residues are remnants or residues in the form of wood fragments being left in the forest. Forest harvesting residues in the form of wood can be in the form of stumps, stems, branches, and short segments which can occur in the felling sites, loading point, and log yards or log ponds. Those residues are left as they are in the forest, whereas the condition of the wood harvesting residues is categorized as good. They can still be utilized for veneer, chip, wood, or activated charcoal products. Wood harvesting residues can also be used to make plywood and other wood types for household furniture and other furniture works that will reduce the amount of timber that needs to be harvested within a year [7].

Wood harvesting practices that are potential to cause residual stand damage in natural forests are tree felling and log skidding. Tree felling technique, which is performed properly in determining the felling direction and making the felling notch, is supposed probably to be able to reduce residual stand damage depending on slopes and stand densities. Low-impact logging system could reduce the damages of residual stand tree [8]. Mugasha et al. [9] stated that selective cutting for fuel woods and logging are reported to be the main drivers of forest degradation.

Management of natural forests has applied the technique of reduced impact logging (RIL). Timber harvesting which applies RIL can minimize wood harvesting residues. Decision support system techniques increased accessibility of marked trees and decreased the length of the road [10]. Appropriate application of logging techniques and stem bucking during timber harvesting will increase the production and quality of wood being produced [11, 12]. Furthermore, Akay et al. [13] reported that the application of an appropriate method of stem bucking could increase the volume by 4.18% and added value by 9.31% for each felled tree. Besides wood harvesting residue and residual stand damage due to timber harvesting, Han et al. [14] stated that the frequency, type, location, and patterns of damage to residual trees vary with stand characteristics, applied harvesting system, forest operations, and planning. Furthermore, they described the following types of residual stand damage: root abrasion and breakage, bole wounds, broken branches, and crown damage.

More efficient utilization of forest as an effort to reduce wood harvesting residue volume in the logging compartment is difficult to be achieved, if it is not accompanied with a policy of incentives and disincentives for forest utilization. Katovai et al. [15] stated that sustainable forest management strategies have achieved some success in reducing forest damage and maintaining the biodiversity and ecological functions needed for spatiotemporal recovery through natural regeneration. The objective of this research was to determine the potency of wood harvesting residue and residual stand damage on timber harvesting in natural forests.

2. Materials and Methods

2.1. Research Site. This research was conducted in October 2018 in the working area of natural forest concession (IUPHHK HA) of PT Austral Byna, Logging block RKT 2018, Logging compartment BL.75. According to the forest management administration, the area belongs to the forestry and horticulture forest service of North Barito District, Central Kalimantan Provincial Forestry Service, and according to the government administration, it belongs to the territory of Barito Utara District, Central Kalimantan Province.

2.2. Materials and Equipment. Materials being used in this research were steel cable slings to help tie the wood obtained from logging, paint, markers, plastic for labelling the trees to be felled, and tally sheets. Equipment used in this research were chainsaws, skidders, tree diameter gauge (phi-band), measuring tape for measuring the diameter and length of logged trees, stopwatches for measuring time, clinometers for measuring slopes, compasses, and digital cameras for documentation.

2.3. Working Procedure

2.3.1. Determination of Sample Plots. In the selected logging compartments in the natural forest concession area, as many as 3 observation sample plots (OSP) measuring 2.0 ha (200 m × 100 m) each were constructed. Positions of the OSPs were designed by systematic sampling with a purposive start, where the first OSP was determined purposively in the selected logging compartment, and the next OSPs were positioned systematically with a distance between OSPs of 100 m, as shown in Figure 1.

Construction of OSP was performed under guidelines from the wood harvesting operational plan with a scale of 1 : 50.000. After the construction of OSPs, there were stand inventories with a diameter of 20 cm or more, for all tree species before logging. Inventory was conducted to validate the report of cruising results.

2.3.2. Data Collected. (1) Primary Data. Primary data were the main data that were obtained by direct observation in the field. The primary data being collected were clear bole wood volume being utilized, wood waste being occurred in the logging compartment, skidding road, and loading point. Figure 2 shows the measured wood harvesting residues comprised, among others, stump, butt, end part wood harvesting residues, and volume of stem which were utilized commonly called clear bole [16].

Each logged tree was coded (or marked in accordance with the tree labels) and the slope around it was measured. Stump residues were defined as the difference between stump height and the allowable felling height, which is 1/3 of the tree diameter at breast height for nonbuttressed trees [17], or stump height was subtracted by the allowable felling height.

Wood harvesting residues being measured in the skidding road were part of the clear bole stems that were left along the skidding road and/or other materials categorized as wood harvesting residues. Wood harvesting residues in

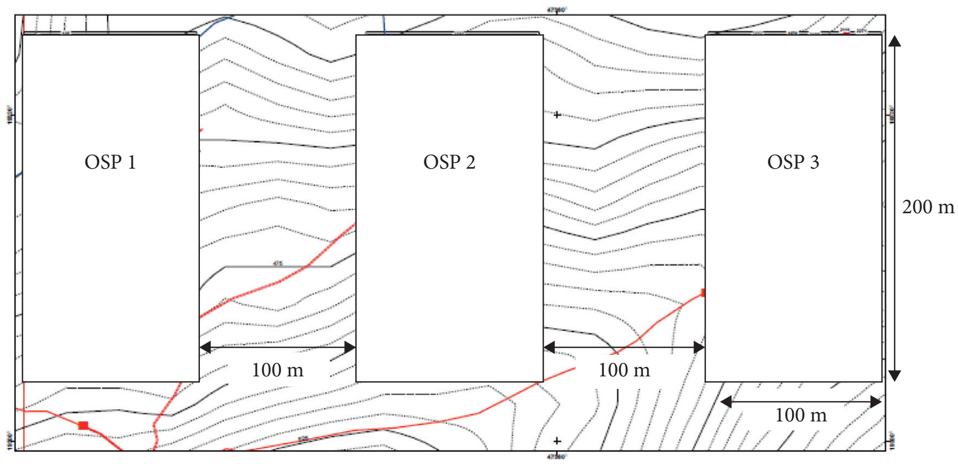

Figure 1: Design of OSP position in the selected logging compartment. Remarks: A = stump wood harvesting residue; B = lower-end residue; C = wood utilized; D = upper-end waste; E = defect; F = clear bole.

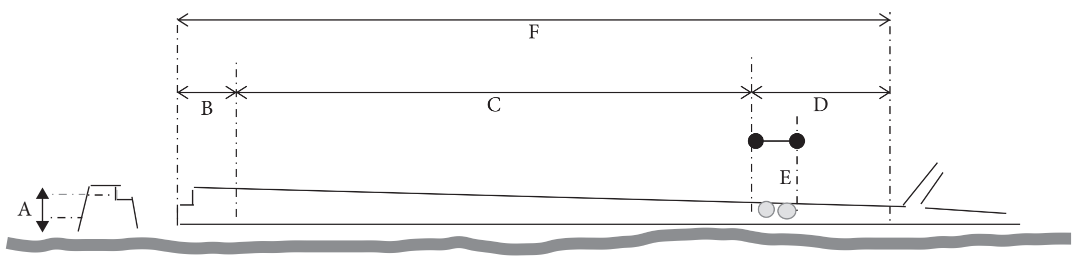

Figure 2: Measurement of wood being utilized and wood waste.

the loading point and wood segments being measured in the logging compartment were originated from the same tree. Wood harvesting residues in the log yard occurred due to trimming of end parts of stems and loading of the wood to transportation equipment. Measurement of residual stand damage was conducted after completion of logging and skidding activities and included the recording of damage and cause and types of damages.

(2) Secondary Data. Secondary data were obtained by examining the archives/data that were available in the research location, comprising, among others, the general condition of the natural forest concession area and forest management and government administrations.

2.3.3. Formatting of Mathematical Components. For the calculation of the volume of waste and stems utilized, we used the empirical formula of Brereton [18] as follows:

$$\mathrm{VL} = \frac{1}{4}\pi\left[\frac{(1/2)(\mathrm{DP} + \mathrm{DU})^2}{100}\right]P, \quad (1)$$

where VL is the volume of waste (m^3), DP is the diameter of the butt (cm), DU is the diameter of the end part (cm), P is the length of the waste (m), 100 is used to convert from m to cm, and π is constant, which is 3.14.

Indexes of logging and skidding were calculated with the following formula:

$$\text{index of felling} = \frac{\text{volume of wood ready to be skidded in logging compartment}}{\text{volume of clear bole stem}},$$
$$\text{index of skidding} = \frac{\text{volume of wood utilized in loading point}}{\text{volume of wood skidded to loading point}}. \quad (2)$$

Percentage of residual stand damage can be calculated with the following formula [19]:

$$\mathrm{LR} = \frac{\mathrm{ND}}{T - \mathrm{Ft}} x\, 100\%, \quad (3)$$

where LR is the level of residual stand damage (%), ND is the number of damaged trees (trees ha^{-1}), T is the number of trees with a diameter of 20 cm up before logging (trees ha^{-1}), and Ft is the number of felled trees (trees ha^{-1}).

3. Results

3.1. General Conditions of the Research Location. Forest stand in the research area was dominated by the tree species of Meranti from the Dipterocarpaceae family, and the rest are mixed jungle tree species and beautiful wood species. Stand density was around 164.91 trees ha^{-1} (for trees with a diameter of 20 cm or more). Most of the tree possesses buttress. Undergrowth vegetation had on average moderate density. The size of the working area of this company was 255,530 ha. Based on inventory results or cruising inventory before logging in Logging compartment BL.75, Logging block 2018 with 100% sampling intensity as large as 100 ha, an average forest potency of 24.27 m^3 ha^{-1} was obtained for a diameter class of >50 cm.

3.2. Volume of Timber and Wood Harvesting Residues. The larger the tree diameter, the greater the volume of wood being utilized. Table 1 shows that OSP 1 with an average of DBH 94.35 m could produce an average volume of wood being utilized as large as 11.52 m^3, which was greater than that in the other two OSPs.

3.3. Efficiency of Timber Harvesting. Efficiency of timber harvesting is mainly affected by the system and technique of timber harvesting. Timber harvesting technique is always related closely to the tree felling stage, which constitutes a component of timber harvesting activities, and to the determination of tree felling direction, tree felling execution, stem bucking, skidding, debarking, and transportation. A correct felling direction and construction of the lowest possible felling notch could minimize wood damage in the logging site.

Recapitulation of the index of logging which is presented in Table 1 shows that the range of index of logging was between 0.80 and 0.84, with an average of 0.81, and it can be concluded that the wood harvesting technique in the research area was not yet good.

3.4. Residual Stand Damage. Results of measurement and calculation of residual stand damage due to tree felling (logging) and skidding are presented in Tables 2 and 3.

4. Discussion

4.1. Volume of Timber and Wood Harvesting Residues. Volume difference in utilized wood was due to diameter, size of trees being felled, and the technical fault during tree felling which caused breaking. Asamoah et al. [7] stated that most of the timber production companies do not know how to manage the wood harvesting residues generated and the wood harvesting residues are left unutilized. In general, 80% of the timber production companies responded that they have an idea of wood harvesting residues management but do not have the technical know-how to manage the wood harvesting residues.

The condition of wood harvesting residues occurring in the research area is presented in Table 4. Table 4 shows that the total average of wood harvesting residues that were good, defected, and broken was 2.121 m^3 (80.952%), with an average volume for good wood harvesting residue condition of 1.038 m^3 (34.808%). The volume of good wood harvesting residues was higher than those volumes of the defect and broken wood harvesting residues. The high potency of wood harvesting residues (34.408%) in good condition constituted an addition of wood raw material. Many of the broken conditions of waste shown in Table 4 were due to technical faults in the felling direction. If the felling direction was correct, and hence there were no broken waste, then there was the addition of raw material potency as large as 1.038 m^3 (34.808%) + 0.601 m^3 (18.563%) = 1.639 m^3 (53,563%). Behjou et al. [20] stated that the percentage of volume loss per cubic meter was significantly different between the two studied harvesting systems. Full-length systems caused a loss equal to 15.6% of a log's volume, while cut-to-length systems lost 35.54% of volume. Bucking damage caused 12.2% volume loss of the logs, which differed significantly from the damage caused during skidding, decking, and loading operations.

Proportion of stem parts that become wood harvesting residues due to logging is presented in Table 5. Table 3 shows that the average volume of total wood harvesting residues from all stem parts was 2.154 m^3 (94.444%). This average consisted of buttress 0.102 m^3 (5.159%), stump 0.375 m^3 $tree^{-1}$ (23.597%), butt 0.855 m^3 (35.930%), and end parts 0.821 m^3 (29.758%). From that wood harvesting residue proportions, it can be seen that the butt part produced higher waste, followed by end parts and stump parts. Considering the condition of those stem parts that were potential to become wood harvesting residues, it can be concluded that the wood harvesting residues occurred due to technical faults. Butt waste was the lower part of the stem which was broken due to fault during cutting and felling of the tree. End part waste occurrence was frequently due to breaking when the tree fell to the valley, while stump waste occurrence was due to lack of skill of the chainsaw operator. In this research, the occurrence of waste was dominated by technical faults. Mederski et al. [21] stated that, in the case of all remaining timber with a diameter of over 20 cm, of particular importance is the fact that there are significant levels of timber harvesting residues (tree tops). This also points towards certain limitations to harvester use in the processing of oak with larger diameter branches.

4.2. Efficiency of Timber Harvesting. The low index of logging was due to the skill of the chainsaw operator which was still low, and the company has not performed intensive training and refreshing skills for the operator. This phenomenon can be seen from field observations where trees with large diameter were difficult to fall due to the felling notch which was not wide enough, and the average height of the stumps being created was high (87.261 cm), which was categorized as high, approaching one meter.

Measurement result of the index of skidding was on average 0.981, with a range between 0.97 and 1.00 as shown in Table 1. Table 1 shows that, in the log yard, there were still

Table 1: Average volume of wood being utilized and the wood harvesting residues.

OSP/topography	Tree identity		Utilized wood	Stump height	Wood harvesting residues	Index of felling	Index of skidding
	Buttress (cm)	DBH (m)	Vol (m^3)	Vol (cm)	Vol (m^3)		
1	101.20	94.35	11.52	92.80	2.55	0.81	0.97
2	113.92	78.58	7.49	84.08	2.22	0.80	1.00
3	98.50	82.50	8.63	84.90	2.15	0.84	0.98
Average	104.539	85.144	9.212	87.261	2.310	0.812	0.981

OSP: observation sample plot; DBH: diameter at breast height; Vol: volume.

Table 2: Stand damage due to felling.

Logging compartment/ OSP		Topography	Stand (20 cm up)	Logged (felled)	Stand damage							
					(tree)	(tree)	Crown (tree)	Broken (tree)	Stem injury (tree)	Fall down/ slanting (tree)	Total (tree)	(%)
BL75	1	Steep	105	10	0	2	0	0	2	2.11		
	2	Level	94	12	1	2	0	2	5	6.10		
	3	Steep	110	10	1	2	1	4	8	8.00		
	Average		103	11	1	2	0	2	5	5.40		

Table 3: Average stand damage due to skidding in PT Austral Byna.

Logging compartment/ OSP		No.	Stand (20 cm up)	Logged tree	Stand damage						
					(tree)	(tree)	Buttress injury (tree)	Stem injury (tree)	Fallen/slanting (tree)	Total (tree)	(%)
BL.75	1	Steep	105	10	1	1	2	4	4.21		
	2	Level	94	12	3	2	2	7	8.54		
	3	Steep	110	10	2	2	3	7	7.00		
	Average	103	11	2	2	2	6	6.58			

Table 4: Condition of wood harvesting residues occurring in the research area.

OSP	Condition of wood harvesting residues							
	Good		Defected		Broken		Total	
	(m^3)	(%)	(m^3)	(%)	(m^3)	(%)	(m^3)	(%)
1	1.331	30.39	0.628	27.759	0.855	13.275	2.814	71.43
2	1.371	26.528	0.586	28.405	0.722	16.495	2.679	71.429
3	0.414	47.501	0.232	26.580	0.226	25.920	0.871	100.00
Average	1.038	34.808	0.482	27.581	0.601	18.563	2.121	80.952

Table 5: Proportion of stem parts that were potential to become wood harvesting residues.

OSP	Waste volume									
	Buttress		Stump		Butt		End part		Total	
	(m^3)	(%)	(m^3)	(%)	(m^3)	(%)	(m^3)	(%)	(m^3)	(%)
1	0.111	4.552	0.534	31.004	1.009	40.568	0.898	23.877	2.552	100
2	0.131	7.362	0.274	16.815	0.842	26.730	0.978	32.426	2.225	83.333
3	0.065	3.564	0.317	22.972	0.715	40.492	0.587	32.972	1.684	100
Average	0.102	5.159	0.375	23.597	0.855	35.930	0.821	29.758	2.154	94.444

wood harvesting residues during the skidding process and during scaling and grading, namely, on an average of 2% of the volume of the skidded wood. Moreover, Poudyal et al. [22] stated that Queensland selective logging has less volume recovery (52.8%) compared to Nepal (94.5%) leaving significant utilizable volume in the forest. Further, they stated that stump volume represents 5.5% of the total timber volume in Nepal and 3.9% in Queensland with an average stump height of 43.3 cm and 40.1 cm, respectively. Kessels and Amoah [23] reported that merchantable residue quantity was 742.57 m^3 (24.69%). Lopes and Pagnussat [24] pointed out that a lower performance rate was expected in the execution of the operation during the training period, as the operators were adapted to the new environmental conditions and techniques required for quick decision and uninterrupted operation.

Maurice et al. [25] stated that improving harvesting techniques has the potential to cut wood harvesting residue volumes by 5%. The efficiency measures to enhance forestry operations might have positive socioeconomic impacts, such as increasing the safety of harvesting operations and harvesting timber quality.

4.3. Residual Stand Damage. Badraghi et al. [26] and Klein et al. [27] stated that when developing a feasible harvesting system, the mechanized harvesting machines should be assessed based on their production rates, unit costs, and impact on a forest ecosystem because mechanized harvesting operations can have a long-lasting effect on a residual stand in the forest. Timber products are regarded as products produced from renewable and sustainable environmental resources.

Table 2 shows that the average number of trees having a diameter of ≥20 cm was 103 trees ha^{-1} and of logged trees was as many as 11 trees ha^{-1}. The number of damaged trees with diameter ≥20 cm was on the average of 5 trees ha^{-1}. Forms of damage which often occurred due to logging were broken stems, with an average of 2 trees ha^{-1}, stem injury with average of 0 trees ha^{-1}, and slanting or falling trees with an average of 2 trees ha^{-1}. On the whole, the average number of damaged trees was as much as 5 trees ha^{-1} (5.40%). Average intensity of logging in the research plot was 5 trees ha^{-1}. This value caused residual stand damage to 5 trees ha^{-1}. This implies that each felling of 1 tree ha^{-1} resulted in residual stand damage of 1 tree ha^{-1}. From the observation results, it can be seen that the diameter and tree height were not always linearly related to the percentage of damage of the residual stand damages. This can result from several factors which were, among others, stand density and felling direction which was affected by the chainsaw man performance.

This research showed lower results as compared to that of Dudakova et al. [28] who reported that the highest percentage of damaged remaining trees equal to 20.47% and 23.36% was recorded for harvester forest operations, followed by skidder (19.44%) and animal forest operations with 19.86% and 14.47%. Estok [29] reported that found residual stand damage by skidder was 49.9%. Tavankar and Bodaghi [30] showed that approximately 12.1% of the residual trees were damaged, 1.2% destroyed, and 32% of the damages are caused by felling stage and 68% by skidding stage. Of all damaged trees, 62% belonged to beech, 15% to hornbeam, and 10% to alder. Damages on the tree boles are, respectively, 11% on the stump level, 51% on the first 1 m, and 38% on the upper first 1 m. Damage sizes vary depending on the logging stages. About 54% of the damage intensity observed bark squeezed and 46% wood damaged. Appropriate silvicultural prescriptions and harvesting technologies can reduce wounding to acceptable levels. Nikooy et al. [31] showed that the highest frequency of damage was observed on trees with a DBH class of 20 cm (24.3%). Most of the stand damage occurred on the bole (55%) of trees, with wound sizes ranging from 50 to 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%).

Stand damage was due not only to felling, but also to skidding as shown in Table 3. Table 3 shows that the number of trees damaged due to skidding ranged between 4 and 7 trees (4.21–8.54%) with an average of 6 trees ha^{-1} (6.58%). This research result showed that the types of stand damage were dominated by buttress and stem injuries and fallen trees. On the whole, the residual stand damage due to logging and skidding was 12 trees ha^{-1} (11.98%). These figures are categorized as light damage levels. The results showed that along the winching strips, the percentage of damage to the residual stand was 19.5 and 18%, while the damage along skid trails reached 25.4 and 31% in the tree length and cut-to-length methods, respectively. The results of this study suggest that damage to the residual stand is considerable and should be reduced to improve the quality of the stand in the future [32]. System harvester forwarder and chainsaw yarder produced greater impact on the surface of the damage, number of remaining trees, crown damage, and damage under 30 cm. Damage to stems above 30 cm was greater in both systems, being greater than that produced by the chainsaw yarder. Root damage was produced only by the chainsaw-skidder system, with 2.4% of damage [33]. Research result by Yuniawati and Dulsalam [34] revealed that the average number of residual stands (trees with a diameter of ≥20 cm) damaged by logging is 26 trees (13.00%) per ha with details of damage to canopy of 4 trees (15.39%), broken branches of 13 trees (50.00%), the trunk wound of 2 trees (7.69%), and the collapsed/tilted of 7 trees (26.92%). Damage to the residual stand in felling is caused more by the lack of skilled chainsaw operators in determining felling direction.

Cut-to-length logging system requires a denser trail network, the area under trail occupied 9.5% of the stand. In late thinning using tree-length logging system, the area under skid trails accounted for 5.6% of the total stand area. Much less damage to the trail was found in the short wood harvesting system, the ruts were shallower than after wood transportation by skidder [35]. Damage to residual trees was generated for 7.4% and 6.9% of residual trees in felling and yarding operations, respectively. Damaged direction of scars was located in front-side (38.9%) and upside (34.7%) for felling operations, while the highest scar damage was found on downside (44.6%) for yarding operations. Scar heights of felling damage were higher than those of yarding damage. In the yarding operation, most of the scars were located within 10 m from the center of the skyline corridor [14].

Loss of biodiversity in managed natural forests may be caused by several factors. Certain species of plants and animals may be unable to tolerate the disturbance caused by forest management and harvesting activities, and subsequently leave the area. Other species may not survive habitat modifications caused by forest harvesting practices: for example, canopy-dependent species may be unable to crossroad openings and become cut off from a resource critical to their survival [36]. The impact on the environment, especially on soil and residual trees, is an important aspect to be considered in the planning and execution of forest operations [37].

Fortini et al. [38] results from monitoring of harvesting operations show that the demographic consequences of selective harvesting were small and likely a result of some damage from nonmechanized operations in relatively vine-free forests. Most evaluations of stock recovery rates in tropical forests are below 50% based on estimated yields following a first harvest, casting doubt over the feasibility of long-term sustainable timber management.

5. Conclusion

The average volume of wood being utilized was 9.212 m^3 $tree^{-1}$ (79.96%) and the average volume of wood harvesting residues was 2.310 m^3 $tree^{-1}$ (20.04%). The total average of wood harvesting residues which were good, defected, and broken was 2.121 m^3 (80.952%), with an average for good wood harvesting residue of 1.038 m^3 (34.808%). Proportions of wood harvesting residues were 2.154 m^3 (94.444%) consisting of buttress as large as 0.102 m^3 (5.159%), stumps as large as 0.375 $m^3 tree^{-1}$ (23.597%), butt as large as 0.855 m^3 (35.930%), and end part as large as 0.821 m^3 (29.758%). The average number of trees with diameter of 20 cm and above which were damaged due to felling and skidding was 5 trees ha^{-1} (5.40%) and 6 trees ha^{-1} (6.58%), respectively. The potential for wood harvesting residues that are in good condition at PT Austral Byna is quite a lot so it has the potential to be utilized.

Data Availability

The data are not freely available, and acceptable justifications for restricting access need legal and ethical concerns of Center of Forest Product Research and Development, Ministry of Environment and Forestry, Republic of Indonesia.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Sona Suhartana, Yuniawati, Seca Gandaseca, Dulsalam, Soenarno, and Jegatheswaran Ratnasingam designed the study, developed the methodology, performed the experiment, analysed the data, and wrote the manuscript. Seca Gandaseca is responsible for editing the manuscript.

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