Trial performance of the zero waste harvesting method in three forest concession companies, Central Kalimantan Province, Indonesia

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Abstract. Currently, natural forest management companies (concession permit of timber forest products utilization-natural forest/IUPHHK-HA) have implemented Reduced Impact Logging (RIL) technology but timber harvesting is still carried out using the conventional method. Tree length logging is an alternative method of harvesting wood in an effort to reduced waste and increase the efficiency of the utilization of timber forest products and the preservation of natural production forests. The potential for wood harvesting waste is estimated at 2.21 million m³/year and has remained left in the cutting compartment for decades. The purpose of this paper is to obtain technical and financial information about forest harvesting on a zero waste basis. Data collection was carried out by experimental methods. Productivity, efficiency, cost, and stand damage data were collected. The results of the research in three IUPHHK-HA in Central Kalimantan show that the zero waste logging method can reduced harvesting waste by 5.1% and increase the efficiency of wood utilization from 87.7-92.8%. Another advantage of the zero waste logging method is that the additional waste from the trunk above the first branch is about 5.8%. The productivity of the conventional method averaged 26.333 m³/hour at a cost of IDR 33,941 m⁻³ while the tree length logging method was 27.320 m³/hour at a cost of IDR 35,251 m⁻³. It is suggested that the tree length logging method be implemented in natural production forest harvesting.

1. Introduction
Currently, timber harvesting has a strategic role because it does not only determine the production of logs produced and the occurrence of waste [1]. Although timber harvesting activities have been carried out using RIL technology, the application in the field is still conventional. This is reflected in tree felling activities which are still fully entrusted to loggers (chainsaw operators). As a result, the division of the stems was carried out based on the ease of cutting the stems so that the efficiency of wood utilization was not optimal, the occurrence of logging waste, and excessive stand damage. The amount of wood utilization efficiency ranges from 77-89% with an average of 87% and the amount of wood harvesting waste ranges from 11-23% or an average of 17% [2]. Meanwhile, the damage to stands that occurred ranged from 17-40% [3].

The correct felling and bucking will increase the quality of the wood and the income from the sale of the wood so that it has an impact on the cost of cutting technically [4]. The felling technique followed by proper bucking will affect the efficiency of utilization and the quality of the wood produced [5]. The application of the proper bucking method can increase the volume by 4.18% with the added value of the
trees felled by 9.31% regarding logging. The perfection of making the fall and back cut notches will affect the efficiency of wood utilization. From a non-technical perspective, there are various possible factors causing the high waste of wood harvesting, low efficiency of wood utilization, and large damage to standing stands [6].

Starting from the description above, it is necessary to research that leads to an improvement in the timber harvesting method, namely the tree length logging method. The most principal thing in the tree length logging timber harvesting method is that the tree length logging system is improved at the landing places after the process of testing and measuring logs by authorized technical officers [8].

2. Materials and Methods

2.1. Materials

This research was conducted in 2017 at three IUPHHK-HA areas namely PT Sarmiento Parakantja Timber (PT A), PT Dwima Jaya Utama (PT B) and PT Erna Djulawati (PT C) in Central Kalimantan. The location of the geographical of PT A area is 111°55'-112°19' East Longitude and 1°12'-1°46' South Latitude; PT B area is 112°39'11''-113°35'00'' East Longitude and 0°50'16''-112°39'11'' South Latitude; and PT C area is 111°30'00''-112°07'30'' East Longitude and 00°52'30''-01°22'30'' South Latitude. Administratively, PT A is located in the district of Kotawaringin Timur, Katingan and Seruyan; PT B in Gunung Mas district and PT C in Seruyan District, Central Kalimantan Province. Topographical condition of PT A ranges from flat to sloping; PT B is sloping to steep and PT C is flat to very steep. The materials used in this study are tree trunks that are felled and ready for a skid, slings for bundling waste wood, lime, markers, diesel fuel, lubricating oil, tally sheets, and questionnaires. The tools used in this study were chainsaws, tractor logs, measure-tapes to measure the diameter and length of the tree being felled, a stopwatch to measure time and a digital camera.

2.2. Methods

The procedure for conducting research in the field is carried out in the following steps (1) determine three forest exploitation company units (IUPHHK-HA) pro-positively and select three sample cutting plots representing different levels of experience of chainsaw operators, (2) on the selected cutting plots, two trial plots (PCP) measuring 100 m x 300 m were made purposively, (3) the first PCP for tree length logging method treatment and the second PCP for control (conventional method), (4) record the potential of all tree species with a diameter of 20 cm up for each PCP, (5) carrying out felling, skidding and counting the number of damaged trees in the PCP, (6) carry out measurements of the volume of wood utilized, volume and quality of wood harvesting waste at each PCP and at the landing places (TPn), and record the number of trees damaged by felling and skidding. Primary data and secondary data were collected in this study. Primary data were collected by observing and measuring the potential of clear bole waste, wood utilized, wood waste above branch free branches, time skidding, residual stands before felling, and skidding and observing the damage to residual stands after skidding. Observation of the potential of stands at tree level (a plant that has a trunk diameter of 20 cm and up) was carried out a census in the observation plot. Schematically the placement of the test plots is presented in Figure 1.
Figure 1. Schema of placement of the trial plots.
The amount of damage to the standing stands and the result of logging and skidding activities and the criteria used is the formula according to Elias [9] as follows:

\[ K = \frac{\sum^b Kr}{\sum^b Ka} \times 100\% \]  
(1)

where:
- \( K \) = percentage of damage to residual stands (%)
- \( \sum^b Kr \) = number of trees with a diameter of more than 20 cm damaged by felling
- \( \sum^b Ka \) = number of trees with a diameter of more than 20 cm that is healthy before felling

To estimate the degree of tree damage due to timber harvesting parameters [10] are used as follows:

a. tree crowns are damaged >30% or large branches are broken
b. wounds on the trunk to damage the cambium >25% around the tree with a wound length of ≥1.5 m
c. the roots are cut or >25% of the buttresses are damaged
d. broken stems and/or collapsed

Trees are considered damaged if they experience one or more of the conditions mentioned above. The criteria for stand damage based on the percentage of tree damage are used as follows [9]:

a. residence is called lightly damaged if the damage is <25%
b. residential residence is called moderate damage if the damage is 25-50%
c. the residence is said to be seriously damaged if the damage is >50%

To calculate the volume of wood and logs used is as follow:

\[ V = \frac{1}{4} \pi \left[ \frac{Dp + Du}{100} \right]^2 \times P \]  
(2)

where: \( V \) = Volume of wood (m³); \( Dp \) = Diameter of base (cm); \( Du \) = End diameter (cm); \( P \) = Length of the sortimen (m); \( \pi \) = Constant (3.14)

The efficiency of wood utilization is calculated by the following formula:

\[ EF = \frac{VA}{VB} \times 100\% \]  
(3)

where: \( EF \) = Wood utilization efficiency (%); \( VA \) = volume of wood utilized (m³/tree); \( VB \) = total potency of clear bole (m³/tree)

Work productivity is calculated using a formula as follow:

\[ P_{tp} = \frac{Va}{W_{tp}} \]  
(4)

where: \( P_{tp} \) = skidding productivity (m³/hour⁻¹); \( Va \) = wood volume (m³); \( W_{tp} \) = skidding time (hour)

Timber harvesting costs were calculated using FAO [11].

3. Results and Discussion

3.1. Timber harvesting waste and wood utilization efficiency

Table 1 shows the average of the wood harvesting waste in Zero Waste Logging (ZWL) method is lower (ranged from 3.8-9.1% with an average of 5.8%) rather than that in Conventional Logging (CL) ranged from 119-153% with an average of 12.3%. This indicates that the ZWL method is more efficient than the conventional method. There are differences in timber harvesting waste for each company due to differences in skidding operators, company management, and field conditions.
The quality of wood harvesting waste is presented in Table 2. It shows most of the waste in ZWL was broken (39.5%) followed by rot (38.5%) and a small part is in good condition (22.0%). This is CL was rot (49.7%) followed by rupture (36.3%) and a small number was in good condition (14.0%).

**Table 1. Logging waste.**

| No. | Forest Concessions | CL | Tree length logging | Wood waste on top of branches |
|-----|--------------------|----|----------------------|------------------------------|
|     |                    | The potential of clear bole | Clear bole waste (m³/tree) | Clear bole waste (m³/tree) | (m³/tree) (%) |
| 1.  | PT A               | 8.182 | 0.977 | 11.9 | 6.48 | 0.306 | 4.7 | 0.285 | 4.4 |
| 2.  | PT B               | 7.717 | 0.995 | 12.9 | 5.948 | 0.527 | 8.9 | 0.539 | 9.1 |
| 3.  | PT C               | 5.448 | 0.835 | 15.3 | 5.152 | 0.423 | 8.2 | 0.198 | 3.8 |
|     | Average            | 7.043 | 0.863 | 12.3 | 5.86 | 0.419 | 7.2 | 0.341 | 5.8 |

**Table 2. The quality of logging waste.**

| Logging methods | Forest Concessions | Quality of logging waste | Good (m³/tree) (%) | Decay (m³/tree) (%) | Broken (m³/tree) (%) |
|-----------------|--------------------|--------------------------|--------------------|---------------------|----------------------|
| PT A            | CV                 | 0.292 | 29.9 | 0.229 | 23.4 | 0.456 | 46.7 |
| PT B            | CV                 | 0.183 | 18.4 | 0.424 | 42.7 | 0.387 | 38.9 |
| PT C            | CV                 | 0.148 | 17.7 | 0.412 | 49.3 | 0.276 | 33.0 |
| Average         | CV                 | 0.208 | 22.0 | 0.355 | 38.5 | 0.373 | 39.5 |
| PT A            | TLL                | 0.049 | 15.9 | 0.139 | 45.4 | 0.118 | 38.7 |
| PT B            | TLL                | 0.041 | 7.8  | 0.321 | 60.9 | 0.165 | 31.3 |
| PT C            | TLL                | 0.077 | 18.3 | 0.180 | 42.7 | 0.165 | 39.1 |
| Average         | TLL                | 0.056 | 14.0 | 0.214 | 49.7 | 0.149 | 36.3 |

The efficiency of wood utilization is presented in Table 3. It shows the timber harvesting efficiency of the ZWL method ranges from 91.1-95.3% or an average of 92.8% higher than conventional which ranges from 84.7-88.1% with an average of 87.7%. It means the average ZWL method of wood harvesting waste is 7.2% and the conventional method is 12.3%. The statistical test results with the smallest significant difference in Table 4 show that F_{\text{count}} = 8.977 is greater with F_{0.05} (1.15) = 4.54, meaning that there is a significant difference in the efficiency of wood utilization between the TLL method and the conventional method.
Table 3. Wood utilization efficiency.

| No. | Forest Concessionaries | CL                | ZWL                |
|-----|-------------------------|-------------------|--------------------|
|     |                         | The potential of clear bole | Wood utilized | The potential of clear bole | Wood utilized | Wood utilized efficiency | Wood utilized | Wood utilized efficiency |
|     |                         | (m³/tree)         | (m³/tree) | (%)     | (m³/tree) | (%)     | (m³/tree) | (%)     |
| 1.  | PT A                    | 8.182             | 7.205     | 88.1    | 6.480     | 95.3    | 6.174     | 91.1    |
| 2.  | PT B                    | 7.717             | 6.722     | 87.1    | 5.948     | 91.1    | 5.421     | 91.8    |
| 3.  | PT C                    | 5.448             | 4.613     | 84.7    | 5.152     | 91.8    | 4.729     | 92.8    |
|     | Average                 | 7.043             | 6.180     | 87.7    | 5.860     | 92.8    | 5.441     | 92.8    |

Table 4. The least square different test of log utilization efficiency.

| Source             | Sum of Squares | Degree of freedom | Mean Square | Fcalculation | Significant |
|--------------------|----------------|-------------------|-------------|--------------|-------------|
| Corrected Model    | 176.842        | 3                 | 56.947      | 3.666        | 0.044       |
| Intercept          | 123345.949     | 1                 | 123345.949  | 7670.611     | 0.000       |
| Harvesting methods | 144.360        | 1                 | 144.360     | 8.977        | 0.011       |
| Error              | 192.964        | 12                | 16.241      |              |             |
| Total              | 128297.635     | 16                |             |              |             |
| Corrected Total    | 369.806        | 15                |             |              |             |

Remark: R squared = 0.478 (Adjusted R squared = 0.348)

Even though the trial of the ZWL method has not been able to reduce the occurrence of wood waste according to the maximum allowable of 5% [12] but additional trunk above the first branch (BAC) waste is obtained ±5.8% or an average of 0.341 m³/tree. It is suspected that the chainsaw and skid tractor operators have not been used to using the ZWL method to reduce the maximum amount of waste. In general, chainsaw operators still practice the process of bucking stems based on the consideration of ease of cutting the tops and ends of fallen trees (topping off). As a result, a lot of clear boles (BBC) waste is left on the cutting plot. However, in the ZWL method, the chainsaw operator must perform branching (delimbing) and cutting the trunk above the first branch to a minimum diameter of 30 cm. Another cause is the habit of chainsaw operators cutting trees in a standing position, which results in more delinquent waste. The average height of the arrears in conventional logging is 81 cm and in the zero waste-based methods it is 0.74 m above the soil surface. The maximum height of arrears varied from 30-50 cm above ground level [13].

3.2. Productivities and costs
The productivity and costs of timber harvesting with the ZWL and conventional methods are presented in Table 5. It shows the productivity of the ZWL method ranges from 23.935-31.689 m³/hour⁻¹ with an average of 28.932 m³/hour⁻¹ or an increase of ±11.6% compared to conventional harvesting which ranges from 21.989-28.774 m³/hour⁻¹ with an average of 25.925 m³/hour⁻¹. However, economically, the cost of harvesting wood is the ZWL method. Thus, technically the application of the ZWL method is considered feasible to be applied by the logging companies.
Table 5. Productivities and costs of log skidding.

| IUPHHK-HA | CL | ZWL |
|-----------|----|-----|
|           | Productivity (m$^3$ hour$^{-1}$) | Cost *) (Rp m$^3$) | Productivity (m$^3$ hour$^{-1}$) | Cost *) (Rp m$^3$) |
| PT A      | 28.774 | 28,052 | 31.172 | 31,523 |
| PT B      | 31.288 | 37,018 | 23.562 | 32,399 |
| PT C      | 21.989 | 36,753 | 23.935 | 41,830 |
| Average   | 27.320 | 33,941 | 26.223 | 35,251 |

Source: Report on the results of research on natural forest wood harvesting techniques based on zero waste and environmentally, 2017

Note: *) Does not include felling costs; Average skid distance between conventional method is 167 m and zero waste method is 158 m

Thus, it can be interpreted that technically and economically, in a flat-topographic area, the application of the zero waste-based methods is considered feasible and the potential for harvesting waste can be transported to the landfill at no cost. On a flat and sloping topography, the skid trail does not bend much so the skid tractor does not maneuver much during the extraction of logs. Even though the zero waste-based methods of harvesting waste are already in the landing places to be transported to the wood processing industry, it requires high costs depending on the distance of the transport, the capacity of the means of transportation, and the conditions of the road.

3.3. Residual stand damages

The results of the observation of the average stand damage from the three IUPHHK-HA showed that the average degree of stand damage did not differ between the ZWL method which ranged from zero waste based to 36.9% and the CL method of 38.40% (Table 6).

Table 6. Residual stand damages caused by felling and skidding.

| No. | Discription | CL | ZWL |
|-----|-------------|----|-----|
|     |             | PT A | PT B | PT C | Average | PT A | PT B | PT C | Average |
| 1   | Poency (Trees up to 20 cm in diameter ha$^{-1}$) | 72  | 72  | 79  | 74.33 | 84  | 84  | 89  | 85.50 |
| 2   | The result of felling | 14.3 | 28.6 | 15.7 | 19.5 | 17.3 | 24.7 | 12.5 | 18.2 |
| 3   | Skidding results | 20.8 | 18.9 | 17.1 | 18.9 | 17.3 | 20.0 | 18.8 | 18.7 |
|     | Total degree of damage to stands due to timber harvesting (%) | 35.0 | 47.4 | 32.9 | 38.4 | 34.7 | 44.7 | 31.3 | 36.9 |

Source: [14]

The significant damage to stands was caused by the low skills of the chainsaw operators and the lack of comprehensive application of RIL technology in the field. The role of these standing stands is very important for the sustainability of timber production and forest sustainability. The greater the degree of damage to standing stands, the riskier it is for the threat of forest sustainability.

Zero waste wood on a flat and sloping topography is technically, economically and ecologically quite prospective. However, due to the limited number of IUPHHK-HA samples, it is still small, it needs to be tested under various management conditions with an operational scale and a rather steep, and steep area topographical condition.

4. Conclusion

The ZWL method can reduce wood harvesting waste by 5.1% and increase the efficiency of wood utilization from 87.7% to 92.8%. Another advantage of the tree length logging method is that the additional waste from the trunk above the first branch is ±5.8%. The productivity of the conventional
method averaged 26.223 m$^3$/hour at a cost of IDR 33,941/m$^3$ while the tree length logging method was 27.320 m$^3$/hour at a cost of IDR 35,251/m$^3$.

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