Reduced impact logging in the dried land natural production forests in Indonesia

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Abstract. Timber harvesting in natural production forests in Indonesia is still carried out to his day in the form of a business license for the utilization of timber forest products-natural forests (IUPHHK-HA). IUPHHK-HA holders have not fully implemented Reduced Impact Logging (RIL). Forest harvesting activities consisting of felling, skidding, bucking, loading, unloading, and transportation of logs are aimed at without significantly disturbing log production and its environment. The purpose of this review is to provide information on RIL in Indonesia. The collection of data was done by using a desk study. Data on productivity, efficiency, costs, damage to the residual stands, and the impact of RIL on emissions were collected. Several research results showed that: (1) logging productivities generally decreased when compared to Conventional Logging (CL), (2) logging efficiency generally increased when compared to CL, (3) logging costs generally increased in the short term, (4) residual stand damages generally reduced when compared to CL, and (5) RIL has potential to reduce emissions compared to CL. It is necessary to do the following: harvest planning such as mapping and distribution of trees, skid trail alignment, design of landings; harvest preparation such as the opening of skid trails, opening of landing places; harvesting such as determining felling direction, felling, skidding, and closure of harvesting such as closure of skid trails and landings.

1. Introduction
Since the 1970s, timber harvesting, which is one of the activities in the silvicultural system in natural forests outside Java, has developed very rapidly, namely the use of modern heavy equipment, all of which are imported from abroad. Regulations and technical guidelines for forest harvesting activities at that time were minimal. It was only after 1972 that several regulations regarding silvicultural systems that could be applied in natural forests were established [1-4].

The area of natural production forest used for timber production is around 56 million ha, consisting of a limited production forest of around 27 million ha and a permanent production forest of around 29 million ha. Of the approximately 59 million ha managed in the form of Business License for the Utilization of Timber Forest Products, 259 units cover an area of 18,809,357.23 ha with wood production of 5,407,235.58 m³ [5]. It is recommended that forest harvesting activities in the Indonesian Selective Cutting and Planting System use Reduced Impact Logging (RIL) techniques. RIL is a systematic approach to planning, implementing, monitoring, and evaluating timber harvesting [6].
Information about RIL has been widely published in various information media, both in the form of books, flyers, presentation materials, and electronic dissemination files. It is hoped that the application of RIL techniques in forest harvesting can minimize the impact of harvesting that occurs on damage to stands, damage to soil, and decrease in biodiversity. However, the attention of holders of IUPHHK-HA is still lacking, this is characterized by the limited willingness of IUPHHK-HA holders to implement RIL in harvesting activities. The lack of attention from IUPHHK-HA holders to the application of RIL is because the holders of IUPHHK-HA for natural forests do not understand the benefits or advantages of implementing RIL in the context of preserving the forests they manage.

There are many benefits when IUPHHK-HA holders apply RIL, namely (1) reducing damage to logged wood so that in turn wood production increases (by 20%), (2) reducing soil damage on the forest floor (15%) so that the productive area is maintained and erosion is reduced, (3) reducing damage to standing stands (10%) thereby increasing the potential for future stands (including stands to be harvested in the next rotation), (4) reducing the deterioration of water and air quality, (5) reducing harvesting costs, (6) reducing Green House Gas (GHG) emissions resulting from logging activities and simultaneously contributing to climate change control [6].

Forest harvesting activities which consist of felling and skidding are carried out without disturbing the logs produced and the environment, which means that they are discussed in the following chapters in this section. The purpose of this paper is to provide general direction to all IUPHHK-HA holders in implementing RIL in the field to obtain improvements in existing road construction, felling and skidding practices that require good insight and skills from the operators as well as policies regarding the supporting environment which aims to reduce damage to land and residual stands.

2. Materials and Methods
2.1. Materials
The materials used in this study were statutory regulations and research results on forest harvesting in Indonesia, stationery materials and computers.

2.2. Methods
The research method is carried out through the following stages (1) heirloom materials will be collected in January 2021, the location of the library collection is in Bogor, (2) synthesize the compiled reference materials based on RIL and CL on logging and skidding activities, (3) data processing is carried out with the tabulation method. The analytical tool used is average.

3. Results and Discussion
3.1. Felling
3.1.1. Felling plan. Harvesting planning starts with a forest inventory and ends with the preparation of a timber harvesting work plan. Forest inventory is an important prerequisite before timber harvesting takes place. Complete and accurate inventory information can be used to plan good timber harvesting. Forest inventory can be carried out in various sampling intensities according to the level of utilization. IUPHHK-HA holders are required to carry out vegetation and contour mapping, followed by a forest inventory to collect various field data. Forest inventory includes, among others: (1) species, potential and distribution of flora; (2) fauna species, potential and habitat; (3) socio-economic and cultural communities; (4) status, use and land cover; (5) soil type and field slope; (6) climate and hydrological conditions, and landscapes; and (7) human resources [7]. In its implementation, the data recording needs to be adjusted according to its purpose. For example, for the annual term, more detailed data are collected.

From the data on the results of the forest inventory, the timber forest product utilization business plan (RKUPHHK) during the expiry of the license, a five year work plan, and an annual work plan are drawn up. The determination of the work plan is then outlined on a small and large scale map. If possible, provide holistic information from satellite imagery or aerial photographs of at least the last two years.
Harvesting planning consists of three phases of activity, namely: mapping the distribution of trees, making the design of the landings, and planning the skid trails as described below [6].

3.1.1.1. Tree distribution map. All that is needed to make a map are a cruising report (LHC) map, a topographic map and a skid trail map. The cruising report is a document legalized by the authorized forestry management which contains tree number, type, diameter and estimated volume of wood from cruising results in the designated area. A topographic map is a type of map that has special characteristics showing the state of the distribution of the earth’s features and its dimensions, marked by a large scale and in more detail. A skid trail map is a type of map that has special characteristics showing a forest road or a tunnel leading to a branch road made only for tractor traffic in log extraction activities. The tree distribution map is based on the LHC on the current year cutting block overlaid on the topographic map and the skid trail trace map. Each tree that is felled is marked with a different symbol/point for the tree to be felled, the tree that is protected, and the core tree. The scale of the tree distribution map is large enough (1:2000-1:5000) so that the point of the tree can be seen clearly [6].

3.1.1.2. Felling directions. The success of felling is largely determined by the right direction of felling the tree. Determination of tree felling direction, is intended to (1) avoid breaking slips on tree trunks/logs as much as possible, (2) minimizing damage to standing stands, and (3) making it easier to skid logs from the cutting compartments to the timber collecting points (log landing places/TPn) on the side freight road. A good direction of felling is to form an angle between 80° in the fin pattern or a parallel position over the skid trail.

The felling direction should take into account the following matters: The felling direction is determined by considering the position of the tree around the tree to be felled to prevent damage to other trees, the slope of the area, the inclination of the tree, and the closest skid trail. The felling direction sign is placed at the base of the tree to be felled in the form of an arrow in the direction of the felling. The felling direction of each tree to be felled is depicted on the tree distribution map [6].

3.1.2. Felling preparation

3.1.2.1. The opening of landing places. The opening of the TPn is carried out at the location that has been planned and following the TPn design that has been made. Top soil is collected in a certain part to be returned at the time of closing of the landings. Do not throw away the land into the water. This can cause soil erosion. Drainage in the landing area runs well so that water does not stagnate in the landings and water flow does not go to the skid trails.

The location of collecting wood in the forest must be chosen in such a way that in addition to not being too large, the land opening does not cause much sedimentation in the waterways. The sites chosen should be relatively flat, especially on ridges, to allow uphill logging. Hill cutting and excavation should be avoided. The shape of the log collection points and their sizes make it easy to organize the round logs which are skidded and then stacked at the landing which will then be loaded onto the truck. The locations designated as wood collection points must be stated on the work map and numbered to make it easier to carry out supervision. In the TPn area, it is tried to prevent stagnation from occurring.

In relation to the skidding activity, what is meant by the log collection point here is a wood collection point on the side of a forest road that functions to accommodate the skidding timber from the felling area. The characteristics of the landings are as follows (1) its location is on the side of the transportation road, generally on the side of branch roads and branch roads, (2) the place selected as the location of TPn is cultivated to be sufficiently flat and strategic to accommodate the skidded logs from the forest stands and to serve the next stage of transportation, (3) the area of the TPn is adjusted to the volume of wood it accommodates (measuring 25 x 25 m² or 25 x 40 m²), the place for releasing the cargo of skid tools, the place for dividing or cutting the stems, the barking place, the place for gathering wood and the place for maneuvering wooden conveyance, and (4) lands are made before harvesting begins and are equipped with good drainage, (5) TPn is the estuary of the skid trail network, the place where the skid trails end, the place for loading logs in the forest, and the starting point for long-distance wood transportation activities, (6) activities of cutting and dividing stems are usually carried out at the TPn;
and (7) TPn is made not permanent because it is only used temporarily. After the landings are no longer used, it is necessary to take measures to prevent soil erosion in the landings [6].

TPn has the following requirements (1) TPn must be flat and the maximum slope of the field is 6%, (2) the location of the TPn is cultivated on a ridge or embankment, (3) the location of TPn must not be in a protected area, and (4) the location of the landing is not close to the river [6]. TPn is a timber collection point on the side of the transportation road which functions to accommodate skidded logs from the forest. The characteristics of landings are as follows: (1) its the location is on the side of a transportation road, generally on the side of a branch road or main road; (2) the place chosen for TPn must be sufficiently flat and strategic to accommodate the skidded logs from the stand and to serve the next stage of transportation; (3) the size of the TPn is adjusted to the volume of wood it serves, the place for releasing the load of skid tools, the place for cutting off the stems, the barriers for logs, and the place for maneuvering for loading tools and wood transport vehicles; (4) TPn is made before harvesting activities begin and is equipped with a good drainage channel; (5) TPn is the estuary of the skid trail network, the place where the skid trails end, the place for loading logs in the forest and the starting point for long distance wood transportation; (6) the location of the cutting and skinning of wood; and (7) TPn is made for temporary use only [8].

The location for collecting wood in the forest must be chosen in such a way that in addition to not being too large, the land opening does not cause much sedimentation in the waterways. The sites chosen should be relatively flat, especially on ridges, to allow uphill logging. Hill cutting and excavation should be avoided. The shape of the log collection points and their sizes make it easy to organize the round logs which are skidded and then stacked at the landing which will then be loaded onto the truck. The locations designated as wood collection points must be stated on the work map and numbered to make it easier to carry out supervision. In the TPn area, it is tried to prevent stagnation from occurring. The location of the TPn must not be in protected areas, areas that have important culture and High Conservation Value Forest (HCVF) areas, and not near rivers. The plan for the location of the landings that have been defined is marked and limited by using easily recognizable signs.

3.1.2.2. The opening of skid trail. Skid trail opening is carried out at the planned location and in accordance with the skid road alignment map that has been made. It is necessary to make efforts to open the skid trail as little as possible to damage the trees around the skid trail. The width of the skid trail is adjusted to the width of the skidder so as not to cause damage to the soil and high forest stands. Minimize curves in the skid trails to keep the sweeping effect of the slideboards on the stand to a minimum. For evaluation purposes, the tractor operator records and reports any changes to the skid trail of the planned skid trail. The skid road that has been opened is depicted on the skid road map.

The requirements for the construction of a skid trail are basically the same as those required for the construction of a haul road. Aerial photographs or satellite imagery can be used to make skid trail plans as well as a large enough scale topographic map, namely a scale of 1:5000 and if possible it is advisable to use a 1:1000 scale map. From this map, a detailed plan can be made for both the transportation road and the skid trail so that the damage to the remaining stands due to the construction of the transportation road and skid trail is minimal.

Based on wood sorting, the skidding system can be divided into three types [9], namely (1) short wood system in which skidding wood is short, cutting the crown and branches and dividing the trunk at the felling site, (2) tree length system where logs are lengthened, cutting branches and crowns is carried out at the felling site, while the division of stems is carried out at the log collection point, (3) a full tree system in which skidding logs including branches and crowns and cutting branches, crowns, and trunk division are carried out at the log collection point.

The requirements for constructing skid trails are as follows (1) skid trails are designed to follow the contours and keep them straight, (2) avoiding hazardous areas such as steep areas, unstable soils, and marshy or swampy areas, (3) avoiding rivers/ditches/waterways and if forced it is necessary to make a temporary crossing point, (4) designed as effectively as possible, (5) maximum slopes of skid trails are 45%, (6) prohibited from entering protected areas and buffer areas, (7) the shortest possible skid distance; and (8) maximum skid trail width is 4 m [6].
The construction of skid trails is closely related to clearing forest areas. The main parameter of the forest clearing is the intensity of forest clearing (IPWH), which is the ratio between the length of the road (m) and the area (ha) of a work unit (production work area). The amount of IPWH depends on (1) the equipment used, (2) road construction costs, (3) forest standing volume [9]. Skid trail tracing is made by marking the skid trail in the field with paint, labels, or rope. The mark is as clear as possible so that the tractor operator can follow the skid trail plan in the process of clearing the skid trail. At each marked point, the coordinates are recorded as the basis for making the skid road map [9].

3.1.2.3. The clearing of weeds. Clearing of weeds in logging activities consists of clearing the trees from lianas and clearing the base of the trees from weeds such as the following. Clean the trees to be felled from the lianas so that when felling the trees they do not pull other trees around them and the felling direction is according to the plan. Clean the base of the trees to be felled from weeds to make it easier for the operator to make cutting notches [6].

3.1.3. Felling operation. Logging activities, especially in natural forests, have complex characteristics. To improve work effectiveness and safety, the following felling procedures are required: Ensure that the trees to be felled do not grow on, if there is any doubt the tree needs to be checked by sticking the end of the chainsaw perpendicular to the tree trunk. Tunnel sizes exceeding 25% of tree diameter should not be felled; for safety reasons, trees of good quality but very hazardous (multi-rooted and linked to other tree crowns, in rocky and steep areas) should also be abandoned. Trees adjacent to a river buffer zone should be felled in such a way that tree crowns fall outside the buffer zone. Prior to the felling operation, it was ensured that the area around the felled tree was safe and free from lianas and other nuisance plants.

Logging is carried out by taking into account the safety of the operator and the people around him, the integrity of the felled trees and damage to the remaining stands. Making the notch and back cut as low as possible to minimize wood waste. Cutting canopy of fallen trees to minimize damage to remaining stands during skidding. The distribution of stems can be carried out at the felling site or the yard by considering minimizing damage to standing stands and optimizing timber utilization. Each piece of wood to be used must be affixed with a barcode label with the same identification number as the barcode label on the arrears left behind [6].

3.1.3.1. Felling productivity. Table 1 shows that the mean skidding productivity in CL and RIL ranged from 9.62-49.06 m$^3$hour$^{-1}$ and 22.00-60.53 m$^3$hour$^{-1}$. The logging productivity in RIL tends to be higher when compared to the logging productivity in CL. This is easy to understand because the logging process in RIL is quite effective. Besides that felling procedure was carried out to meet the RIL guideline [6].

| No. | Sources | Felling productivities (m$^3$hour$^{-1}$) |
|-----|---------|----------------------------------|
|     |         | CL                  | RIL                  |
| 1.  | [10]    | 39.24               | 25.30                |
| 2.  | [11]    | 18.00               | 22.00                |
| 3.  | [12]    | 36.24               | 32.80                |
| 4.  | [13]    | 16.04               | -                    |
| 5.  | [13]    | 9.62                | -                    |
| 6.  | [14]    | -                   | 60.53                |
| 7.  | [15]    | 49.96               | 42.16                |
| 8.  | [16]    | 38.03               | 45.56                |

3.1.3.2. Felling efficiency. Table 2 shows that the mean felling efficiencies in CL and RIL ranged from 75-95.50% and 86-97%. Average felling efficiency in RIL tends to be higher when compared to logging productivity in CL. This is easy to understand because the felling process in RIL is quite effective.
Table 2. Felling efficiencies.

| No. | Sources | Felling efficiencies (%) |
|-----|---------|--------------------------|
|     |         | CL          | RIL          |
| 1.  | [17]    |             | 92          |
| 2.  | [12]    | 86.56       | 89.36       |
| 3.  | [18]    | 75          |             |
| 4.  | [19]    | 86          |             |
| 5.  | [20]    |             | 97          |
| 6.  | [15]    | 95.50       | 96.60       |
| 7.  | [21]    | 80          |             |
| 8.  | [22]    | 83          |             |
| 9.  | [23]    | 80          |             |
| 10. | [24]    | 80          |             |
| 11. | [25]    |             | 90          |
| 12. | [25]    |             | 90          |
| 13. | [25]    | 84          |             |
| 14. | [25]    |             | 86          |
| 15. | [25]    |             | 87          |

3.1.3.3. Felling costs. Table 3 shows that the average logging costs in CL and RIL ranged from IDR 3,972-8,000 m$^3$ and IDR 1,604-9,150 m$^3$. Average logging costs in RIL tend to be lower when compared to harvesting productivity in CL. This is easy to understand because the felling process in RIL is quite effective to meet the RIL guideline [6].

Table 3. Felling costs.

| No. | Sources | Felling Costs (IDR m$^3$) |
|-----|---------|--------------------------|
|     |         | CL          | RIL          |
| 1.  | [10]    | 8,000       | 9,150       |
| 2.  | [13]    | 3,972       |             |
| 3.  | [13]    | 6,880       |             |
| 4.  | [14]    |             | 1,604       |
| 5.  | [16]    | 4,439       | 3,582       |

3.1.3.4. Residual stand damages caused by felling. Table 4 shows that the average residual stand damage by felling in CL and RIL ranged from 13.47-15.28% and 5.56-9.93%. Average residual stand damage in RIL tends to be lower when compared to the average residual stand damage in CL. This is easy to understand because the felling process in RIL meets the felling procedure [6].

Table 4. Residual stand damages caused by felling.

| No. | Sources | Residual sand damages (%) |
|-----|---------|--------------------------|
|     |         | CL          | RIL          |
| 1.  | [20]    | 13.47       | 8.45         |
| 2.  | [26]    | 15.28       | 9.93         |
| 3.  | [14]    |             | 5.56         |
| 4.  | [27]    | 16.27       |             |

3.2. Skidding

3.2.1. Skidding plan. Skidding is an activity of removing wood from the place where the tree is felled and which has undergone first-degree cutting of the trunk to the log collection point through a skid trail that is not fully prepared. The skidder is carried out by a skidding team using the skidder for wood extraction. Skidding should be carried out as follows (1) the skidding activity follows the skidding plan...
that has been made, (2) ensure that skidding is carried out up the slope, (3) the activity of pulling wood to the tractor body is endeavored by using a cable as long as possible, (4) the maximum incline is 50%, (5) if the skidder must cut slopes, the angle of the skid trail to the contour should not exceed 45 degrees, (6) skidding is carried out when the soil is dry, (7) combing or cutting hills in skidding should not exceed 25%, (8) the turning radius is slightly larger to avoid damaging the standing stands, (9) make a water spurt on the skid trail area where it is estimated that there will be a bigger pool of water, (10) for forced skidding through watercourses, a dividing flow must be made and in the dry season a bridge must be constructed, (11) using bridges of non-commercial timber species, (12) avoiding pushing the ground towards the river bank, (13) avoiding land with soft soil, and (14) optimizing engine power [6].

3.2.2. Skidding operation

3.2.2.1. Skidding productivity. Table 5 shows that the average skidding productivity in CL and RIL ranges from 18.00-39.84 m$^3$hour$^{-1}$ and 15.54-36.69 m$^3$hour$^{-1}$. Average skidding productivity in RIL tends to be higher when compared to average skidding productivity in CL. This is easy to understand because the logging process in RIL is quite effective [6]. In the Amazon forest the productivity of skidding in RIL is higher than the productivity of skidding in CL, which is 31.66 m$^3$hour$^{-1}$ respectively compared to 22.39 m$^3$hour$^{-1}$ [30].

| No. | Sources | Skidding productivities (m$^3$hour$^{-1}$) |
|-----|---------|------------------------------------------|
| 1.  | [10]    | 39.84                                   |
| 2.  | [28]    | 3270                                    |
| 3.  | [11]    | 18.00                                   |
| 4.  | [14]    | -                                       |
| 5.  | [29]    | -                                       |
| 6.  | [29]    | -                                       |
| 7.  | [29]    | -                                       |
| 8.  | [29]    | -                                       |
| 9.  | [29]    | -                                       |

3.2.2.2. Skidding efficiency. The average skidding efficiency according to the literature on CL and RIL is presented in Table 6. It shows that the mean skidding productivity in CL is 92%. Table 6 also shows that the average skidding efficiency in RIL ranges between 96 and 99%. The average skidding efficiency in RIL tends to be higher when compared to average skidding efficiency in CL. This is easy to understand because the logging process in RIL is quite effective [6].

| No. | Sources | Skidding efficiencies (%) |
|-----|---------|----------------------------|
| 1.  | [25]    | -                          |
| 2.  | [25]    | -                          |
| 3.  | [25]    | 92                         |
| 4.  | [25]    | -                          |
| 5.  | [25]    | -                          |

3.2.2.3. Skidding costs. The average skidding costs according to the literatures for CL and RIL are presented in Table 7. It shows that the average skidding costs in CL and RIL ranged between IDR 26,000-51,000 and IDR 16,000-34,100, respectively. Average skidding cost in RIL tends to be higher when compared to average skidding costs in CL. This is easy to understand because the logging process in RIL meets RIL Guideline [6].
Table 7. Skidding costs.

| No. | Sources | Skidding costs (IDR m⁻³) |
|-----|---------|------------------------|
|     |         | CL                     | RIL                  |
| 1.  | [11]    | 26,000                 | 16,000               |
| 2.  | [31]    | 51,400                 | 34,100               |
| 3.  | [14]    | -                      | 21,142               |

3.2.2.4. Residual sand damages caused by skidding. The average damage to standing stands due to skidding according to the literatures on CL and RIL is presented in Table 8. It shows that the average damage to standing stands due to skidding in CL was 13.47% and the average damage to remaining stands due to skidding in RIL ranges from 8.10-9.59. Average residual stand damages caused by skidding in RIL tends to be higher when compared to average residual stand damages caused by skidding in CL. This is easy to understand because the logging process in RIL is quite effective [6].

Table 8. Residual stand damages caused by skidding.

| No. | Sources | Residual stand damages (%) |
|-----|---------|----------------------------|
|     |         | CL                        | RIL                    |
| 1.  | [20]    | 13.47                     | 8.45                   |
| 2.  | [14]    | -                         | 9.59                   |
| 3.  | [28]    | -                         | 8.10                   |

3.3. Forest harvesting

3.3.1. Efficiency of forest harvesting. The mean forest harvesting efficiency according to literature for CL and RIL is presented in Table 9. It shows that the average skidding damage to remaining trees in CL and RIL ranges between 60.42-84% and 75.30-91.41%. Average logging efficiency in RIL tends to be higher when compared to average logging efficiency in CL. This is easy to understand because the logging process in RIL meets RIL guideline [6].

Table 9. Harvesting efficiencies.

| No. | Sources | Harvesting efficiencies (%) |
|-----|---------|----------------------------|
|     |         | CL                        | RIL                    |
| 1.  | [22]    | 84.00                     | -                      |
| 2.  | [32]    | -                         | 91.41                  |
| 3.  | [25]    | -                         | 89.10                  |
| 4.  | [25]    | -                         | 79.20                  |
| 5.  | [25]    | 77.28                     | -                      |
| 6.  | [25]    | -                         | 84.28                  |
| 7.  | [25]    | -                         | 83.52                  |
| 8.  | [33]    | 60.42                     | 76.30                  |

3.3.2. Costs. The average cost of harvesting forest according to the literature on CL and RIL is presented in Table 10. It shows that the average harvesting cost in CL ranged from IDR 313,803-510,000 while the average harvesting cost in RIL was IDR 296,000. Average logging costs in RIL tends to be lower when compared to logging cost in CL. This is easy to understand because the logging process in RIL meets the reduced impact logging guideline [6].

Revenues for harvesting from the RIL method increase when compared with the revenue for harvesting from the conventional method. The annual increase in RIL method timber harvesting income is IDR 976,030,570.- compared to the conventional method of harvesting wood [37]. This is easy to understand because the logging process in RIL meet the reduced impact logging guideline [6].
Table 10. Harvesting costs.

| No. | Sources | Harvesting costs (IDR m⁻³) |
|-----|---------|-----------------------------|
|     |         | CL | RIL |
| 1.  | [34]    | 345,665 | - |
| 2.  | [35]    | 313,803 | 296,000 |
| 3.  | [36]    | 510,000 | - |

3.3.3. Residual stand damages. The mean residual stand damage by harvesting according to references for CL and RIL is presented in Table 11. It shows that the average residual stand damage by harvesting in CL and RIL ranged from 21.96 to 40.71% and 19.08 to 24.37%. Average residual stand damage by harvesting in RIL tends to be lower when compared to average residual stand damage by harvesting in CL. This is due to the fact that in RIL: (1) skid trails have been prepared in RIL and (2) the skid trail process is in accordance with the provisions of RIL [6].

Table 11. Residual stand damages caused by harvesting.

| No. | Sources | Residual stand damage by harvesting (%) |
|-----|---------|----------------------------------------|
|     |         | CL | RIL |
| 1.  | [38]    | 33.16 | 19.53 |
| 2.  | [27]    | - | 24.37 |
| 3.  | [8]     | 34.40 | - |
| 4.  | [8]     | 23 | - |
| 5.  | [8]     | 40.71 | - |
| 6.  | [8]     | 21.96 | - |
| 7.  | [38]    | 40.43 | 19.08 |

3.4. The impact of harvesting to carbon emission

The results of research by Bertaultd and Sist, Elias and Lasco in [39] can be drawn the following conclusions: (1) causing a decrease in carbon storage by 22-67%, (2) the rate of CO₂ emission (release of carbon storage from forests) is influenced by the intensity of logging, CL and RIL, and the speed of the macro mass and litter decomposition processes, (3) the application of RIL can reduce vegetation damage by 50% so that in the short term it is able to maintain forest carbon by 12.5-25% greater than CL, and (4) RIL harvesting produces high quality standing stands so that a higher stand growth can be expected in the next cycle.

Based on the dynamics of the number of carbon stores in the CL and RIL areas for 30 years, it can be seen that the rate of increase in the average annual forest carbon storage is as follows [39]: (1) period 0-10 years after harvesting, the rate of increase in carbon storage in the CL area was 1826 tonnes C ha⁻¹ year⁻¹ while in the RIL area it was 3,113 tonnes C ha⁻¹ year⁻¹ or 1.70 times compared to the rate of increased carbon sequestration from CL, (2) 10-30 years after harvesting, the rate of increase in carbon storage in the CL area was 2,207 tonnes C ha⁻¹ year⁻¹ while in the RIL area it was 3,786 tonnes C ha⁻¹ year⁻¹ or 1.72 times the rate of increasing carbon sequestration from CL, (3) during the 10-30 year period after harvesting, the rate of increase in carbon storage in the CL area was 2,483 tonnes C ha⁻¹ year⁻¹ while in the RIL area it was 4,456 ton C ha⁻¹ year⁻¹ or 1.80 times the rate of increasing carbon sequestration from CL. Furthermore, it was concluded that the impact of implementing RIL could increase the absorption capacity of CO₂ from the air to 1.7 times the absorption capacity of CO₂ in the CL area and increase the amount of annual average forest carbon storage in the CL area [39].

If conventional logging is them as a baseline, research indicates RIL can potentially reduce emissions by approximately 1-7 tonnes CO₂ ha⁻¹ year⁻¹ [40]. This may act as the basis for future planned forest management activities involving RIL, carbon, and forest certification through the hierarchy of production forest management. The implementation of both RIL and forest certification can be facilitated through the binding of carbon financial incentives [40].
3.5. Post harvesting activities

Post-harvesting activities include closure of skid trail and landing closures. The skid trail closure is carried out gradually on skid trails that are no longer in use. The closure of the skid trail is intended to reduce soil erosion due to rainwater by making a corner on the closed path, that is, a slope that crosses the path with intensity and slope adjusted to field conditions. Planting lines that have been closed may be replanted [6].

Landing closure is carried out by returning the topsoil to the former landfill area. Planting in the former landfill area is planted immediately to accelerate land rehabilitation. Ensure that there is no waterlogging in the former landings and that there is no direct flow of water from the landings to the river [6].

3.6. Occupational safety and health

Occupational safety and health (K3) are an understanding and an effort to ensure wholeness and perfection, both physically and spiritually, workers in particular and humans in general [41]. From a scientific perspective, K3 can be interpreted as a science whose implementation is an effort to reduce the risk of occupational accidents and occupational diseases. To prevent occupational accidents and disease due to logging, personal protective equipment must be used. Personal protective equipment for logging activities consists of a head cap, ear protection from noise, gloves, and field shoes. A Code of practice for occupational safety and health in forestry has published by ILO in 1998 [42]. The relation to occupational safety and health in timber harvesting is described below.

Governments making national regulations should state that (1) employers have the primary responsibility for occupational safety and health in harvesting work, (2) employers are responsible for implementing and maintaining systems and methods of work that are safe and without risk to health, (3) employers should provide all necessary instruction and training to ensure that workers are competent to carry out timber harvesting tasks safely, (4) employers should establish a system whereby occupational accidents, hazardous events and diseases are reported, recorded and investigated, preventing or reducing the incidence of accidents, hazardous events and diseases due to future timber harvesting, (5) those in charge or primary responsibility such as forest owners, prime contractors, local managers and supervisors - must ensure that the timber harvesting workplace is safe and without risk to health, (6) manufacturers, designers and suppliers of harvesting equipment and materials must take responsibility for ensuring that their products are designed and manufactured so that they are safe and without risk to health, when used appropriately, (7) workers should cooperate with their employer to ensure the fulfillment of duties legally assigned to the employer, (8) workers should be obliged to take all appropriate steps to ensure the safety of themselves and others who may be at risk as a result of their actions or negligence in harvesting wood, (9) measures taken to ensure that there is close cooperation between employers and workers in promoting occupational safety and health in timber harvesting work. Such measures should include the establishment of committees for the promotion of occupational safety and health with representatives of employers and workers, which have well-defined tasks and powers safety and health of timber harvesting. They should endeavor to reduce hazards to, or in the vicinity of timber harvesting workplaces, to the lowest possible level. Employers must ensure compliance with all laws, regulations, and codes of practice for felling trees that are relevant to occupational safety and health. They must develop and apply their own timber harvesting conditions if laws and regulations have not been enacted. Employers must initiate and maintain a work safety culture in the company, including a system of morals and rewards and material incentives for all personnel involved. Employers must ensure compliance with all laws, regulations, and harvesting codes of practice relevant to occupational safety and health [42].

4. Conclusion

A part of forest companies has carried out reduced impact logging in natural production forests. The harvesting activity is carried out in an environmentally friendly manner. Forest harvesting activities which consist of felling and skidding were carried out without causing significant disturbance to the logs produced and the environment. It is necessary to do the following: harvest planning (mapping and
distribution of trees, skid trail alignment, design of landings), harvest preparation (opening of skid trails, opening landing places), harvesting (determining felling direction, felling, skidding), and the closure of harvesting (closure of skid trails, closure of landings) is carried out properly. The application of RIL can increase the efficiency of timber harvesting and can reduce costs and residual stand damages. The efficiency of forest harvesting using RIL and CL were varied from 60.42-84.20% and 75.30-91.41%, respectively. The cost of forest harvesting using RIL and CL were consecutively IDR 313,803-510,000 and IDR 296,000. The residual stand damage caused by forest harvesting in RIL and CL varied from 21.96-40.71% and 19.08-29.37%. RIL has the potential to reduce emissions compared to CL.

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