

# Changes in floristic diversity and stand damage of tropical forests caused by logging operations in North Kalimantan, Indonesia

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**Abstract.** *Matangaran JR, Anissa IN, Adlan Q, Mujahid M. 2022. Changes in floristic diversity and stand damage of tropical forests caused by logging operations in North Kalimantan, Indonesia. Biodiversitas 23: 6358-6365.* Selective cutting of natural forests in Indonesia has been going on for decades. As a consequence, such activities cause disturbances in vegetation cover indicated by changes in diversity and evenness, forest stands damage and mortality of juvenile trees. This research aimed to determine changes in diversity and evenness of vegetation before and after harvesting at seedling, saplings, poles and tree levels, stand damage and forest opening, the number of natural regeneration, and the relationship between felling intensity and forest opening. The research was conducted in a logging concession applying Reduced Impact Logging (RIL) in North Kalimantan by restricting timber cutting to only commercial trees with a diameter of more than 50 cm. The result found 38 tree species in the research plot with average logging intensity of 6.5 trees per hectare. Before and after harvesting, it was found that there were slight changes in diversity and evenness indices at seedling, sapling, pole and tree levels. The percentage of stand damage was 17.8%, and the percentage of forest opening was 19.76 %, which was comparably lower than logging practices in other areas. Nonetheless, we found a strong positive relationship between felling intensity and forest opening. The findings of this study provide another evidence that it is necessary to implement reduced impact logging to reduce damage to forest ecosystems due to selective cutting in the tropical region. It is important to limit the number of trees logged per hectare in order to reduce logging damage and forest opening, minimize impacts on tree species diversity and facilitate natural regeneration.

**Keywords:** Felling intensity, forest opening, logging, natural regeneration, stand damage

## INTRODUCTION

Natural tropical forests almost dominated Indonesian forests in the past. Nonetheless, only 50.9% of forest cover is still remaining in 2020 (MoEF 2022). Deforestation and forest degradation in Indonesia are driven by many factors, including logging, population growth, shifting cultivation, resettlement, road construction, commodity demand, policy, and forest fires (Wicke et al. 2011). Among such drivers, logging in natural forests conducted by forest concessionaires is considered to trigger deforestation and forest degradation, which is often then continued by forest conversion to other land uses, such as monoculture plantations and mining. Deforestation and forest degradation not only reduce the productivity and commercial values from the forestry sector (e.g. timber), but also severely affect ecosystem services delivered by the forest, including the loss of biodiversity (Tsujino et al. 2016).

The tropical forest of Indonesia has a very rich biodiversity, but most of the forested areas have been deforested and degraded (Hamilton 1997). In the context of logging operations, serious damage to vegetation occurs due to the implementation of selective logging (*Tebang Pilih Tanam Indonesia/TPTI*). In doing selective logging in

natural forests, there are several stages usually conducted, including forest inventory, road building, tree felling, and skidding, and log transport. Some disturbances are inevitable when implementing such practices. Timber felling has consequences on the forest cover, including the opening of canopy cover, the creation of gaps and damage to the remaining vegetation around the felled trees. The use of heavy equipment in log extraction also could damage the soil. The movement of the bulldozer to skid the log would open the forest area and disturb natural regeneration and soil (Matangaran et al. 2019a; Matangaran et al. 2019b). Therefore, some improvements have been proposed by Hendrison (1990) to minimize the damage of selective logging on the vegetation, such as improved planning and organization of road networks, controlled directional felling and controlled skidding, and log extraction by winching. These improvements would reduce the total area of forest affected by logging, such as forest opening and disturbance due to felling and skidding.

The disturbance caused by logging operations affects the stand structure and floristic diversity of the residual vegetation. Research in Brazil showed flora diversity and natural regeneration changes due to logging operations (Bezerra et al. 2021). Changes in vegetation diversity and residual stand damage due to logging in the tropics were

also noted in Bolivia (Park et al. 2005), India (Subashree et al. 2021), Central Kalimantan, Indonesia (Blackham et al. 2014), and Kenya (Maua et al. 2020). Besides damaging the residual vegetation, several studies have shown that opening forest areas also impact the regeneration capacity of the forest, such as in the USA. (Brooks et al. 2017; Mohler et al. 2021), Madagascar (Trýzna et al. 2021), Kalimantan, Indonesia (Blackham et al. 2014), India (Subashree et al. 2021), and Borneo (Hayward et al. 2021). The reduction of tree stands caused by timber harvesting and the collateral damage to the residual vegetation also change the carbon stock of the forest (Condé et al. 2021; Saimun et al. 2021; Dangwal et al. 2022), and ground biomass (Borges et al. 2021; Laing et al. 2021). Not only affecting the vegetation, but logging and land conversing also cause damage to the soil and fauna (Wiryono et al. 2022). The use of heavy equipment in timber harvesting and transportation causes soil compaction (Matangaran 2012; Matangaran et al. 2019a). In term of impacts on fauna, logging operation affects the vegetation structure of the forest, which influence the existence of animals, for example, bats activity (Brooks et al. 2017).

The scale of forest stand damage caused by logging operations depends on the intensity of timber harvesting (Matangaran et al. 2019b). Although there have been several studies investigating the impacts of logging on vegetation and the stand structure of the forest, adding more research might be useful to enrich our understanding of this issue, especially in the context of tropical forests in Kalimantan, Indonesia. Therefore, this research aimed to analyze the changes in diversity, stand damage, and natural regeneration before and after selective logging in North Kalimantan Province. In particular, this study focused on

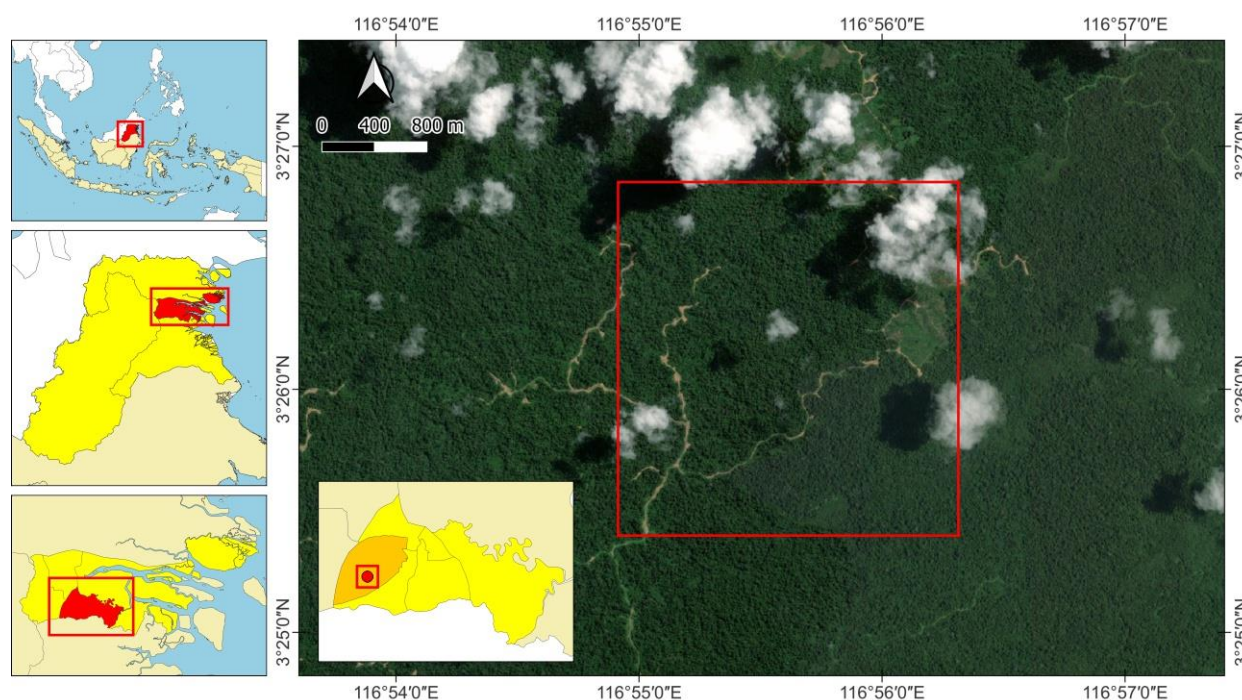
the stand structure of the seedlings, saplings, poles, and trees before and after forest harvesting and the relationship between felling intensity and forest opening and stand damage. We expected the results of this study might serve as a reference for forest management in order to reduce stand damage due to logging operations.

## MATERIALS AND METHODS

### Study area

This research was conducted in a logging concession area in Periuk Village, Betayau Sub-district, Tana Tidung District, North Kalimantan Province, Indonesia. The area lies between 2°48'47" N to 3°37'30" N and 116°30'00" E to 117°11'44" E with elevation ranging from 5 to 1000 m above sea level (Figure 1). The concession area had an extent of 195,110 hectares and was covered by natural forest. The topography is flat to steep, with the soil dominated by podzolic and latosol. The lowest rainfall is 197.4 mm in January, and the highest is 329.8 mm in December. The forest stand structure consisted of an uneven-aged forest dominated by species from the family Dipterocarpaceae.

Timber harvesting was carried out by selective cutting in which only commercial trees with a diameter of more than 50 cm are allowed to be cut. In our study, the felling of the trees was carried out using a chainsaw, skidding using a Cat D7 G bulldozer. Annual allowable cut is 3972 hectares per year. The company applies the Reduce Impact Logging (RIL) technique.



**Figure 1.** Map of study location in a logging concession in Tana Tidung District, North Kalimantan Province, Indonesia

## Methods

### Stand damages

This research analyzed the floristic diversity and stand structure before and after timber harvesting. The research plots were made in the form of a square with a size of 100 x 100 m<sup>2</sup> (one hectare), with a total of 10 (ten) plots. Each plot was divided into 25 sub-plots in which within each sub-plot, we measured the number of individuals on a plot of 20 x 20 m<sup>2</sup> (for tree diameter more than 20 cm), 10 x 10 m<sup>2</sup> (pole), 5 x 5 m<sup>2</sup> (sapling), and 2 x 2 m<sup>2</sup> (seedling).

Changes in floristic diversity were measured from two biodiversity indicators. First, to determine the degree of species diversity, the Shannon-Wiener diversity index was used with the formula as follows:

$$H' = -\sum P_i \ln P_i$$

Where:

H' : Shannon-Wiener diversity index;

P<sub>i</sub> : n<sub>i</sub>/N; n<sub>i</sub>: number of individuals of a species;

N : number of individuals of all species

Second, the dispersion/distribution of the species was measured as the Evenness index using the following equation:

$$e' = H' / \ln S$$

Where:

e' : Evenness index

H' : Shannon-Wiener index

S : number of species found

Tree damage was analyzed by calculating the number of damaged plants at each vegetation stage. The formula to calculate the percentage of vegetation damage was as follows:

Trees damage

$$Tr (\%) = c / (a-b) \times 100\%$$

Where:

Tr : percentage of tree damage (%)

c : number of damaged trees per hectare

a : stand density before the felling per hectare

b : number of logged trees per hectare

Poles damages

$$Pl (\%) = q/r \times 100\%$$

Where:

Pl : percentage of poles damage (%)

q : number of damaged poles after felling

r : number of poles before felling

Sapling damages

$$Sp (\%) = t/u \times 100\%$$

Where:

S : percentage of sapling damage (%)

T : number of sapling damage after felling

u : number of saplings before felling

Seedling damages

$$Sd (\%) = m/n \times 100\%$$

Where:

Sd : percentage of seedling damage (%)

m : number of sapling damage after felling

n : number of seedlings before felling

### Forest opening caused by felling and skidding

Measuring the opening area due to felling of the tree was determined by measuring the area exposed due to the felling of each tree in a sample plot of 100 x 100 m with a total of 10 plots. The parameter measured was the open canopy area due to the felling of each tree trunk. The area exposed due to logging was the sum of the projected tree canopy area before felling, plus the tree canopy area and trunk area measured after the tree fell.

The measurement of the opening area was started from the closest skid trail from the landing site (site for log collection) to the skid trail furthest from the landing site. The observation locations were observed in 10 plots of work area measuring 100 m x 100 m in each plot. The open area due to skidding was measured as the length of the road opened by the bulldozers from each plot. The extent of the opening area due to skidding was the length multiplied by the width of the skid trail. The total area of forest opening was the sum of the opening area due to felling and the area due to skidding. We used regression analysis to determine the relationship between felling intensity and the opening forest area percentage.

## RESULTS AND DISCUSSION

### Tree species and indices of diversity and evenness

There were 38 tree species found in all sample plots (Table 1). The logging concession only logged commercial tree species with more than 50 cm diameter. The most harvested tree species were from Dipterocarpaceae family, including *Shorea smithiana* (red meranti), *Shorea johorensis* (meranti), *Shorea javanica* (white meranti) and *Shorea acuminatissima* (yellow meranti). In this study, only three species from Dipterocarpaceae family (*Shorea johorensis*, *Shorea javanica*, and *Shorea acuminatissima*) were logged.

The Shannon-Wiener (H') species diversity index before and after harvesting showed a range between 2-3, indicating moderate diversity at all levels of growth (i.e. tree, pole, sapling, seedling) (Table 2). There was a slight change in the diversity index between before and after harvesting. The evenness index indicated relatively similar values before and after harvesting.

### Stand damage, felling intensity and forest opening

Felling intensity is defined as the number of trees cut per hectare. In Table 3, the felling intensity in the sample plots varied from 3 trees/ha to 10 trees/ha, with an average of 6.5 trees/ha. The average tree damage per hectare was 9.7 trees. The average percentage of stand damage was

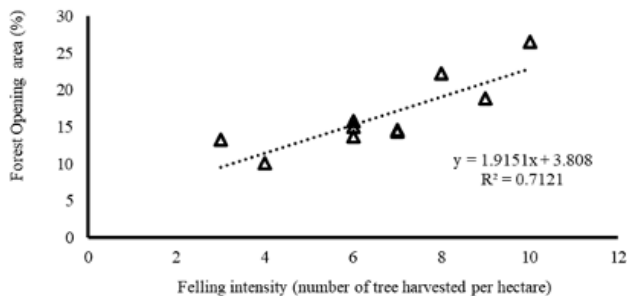
17.8 %, and the average percentage of forest opening was 20.38 %. The density of trees per hectare with a diameter greater than 20 cm, the number of trees cut per hectare, the percentage of damage to the remaining stands in the form of trees with a diameter greater than 20 cm, and the percentage of forest opening due to timber harvesting can be seen in Table 3.

Forest opening in timber harvesting always occurred by the felling gap of felled trees and skid trail by maneuvering the bulldozer. The smaller number of trees cut down, the lower opening by feeling gap and skid trail. We focused on analyzing the relation between felling intensity and the percentage of forest opening because we found out that the average number of trees cut per hectare was 6.5 trees/ha and not more than 10 trees cut per hectare at maximum.

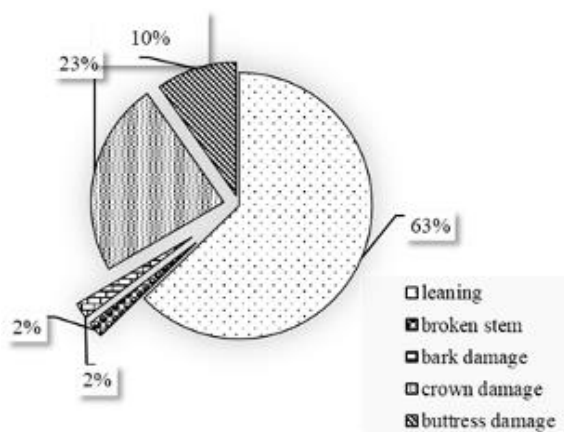
The results of regression analysis showed a strong positive relationship between felling intensity and opening forest areas. The relation can be presented by equation  $Y = 1.9151X + 3.808$  ( $R^2 = 0.71$ ), as shown in Figure 2.

**Type of tree damage and natural regeneration before and after harvesting**

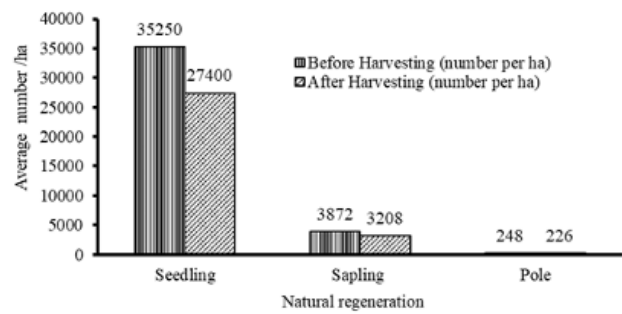
In this research, five types of tree damage occurred as a result of timber felling. The leaning tree was the most dominant tree damage, which occurred in 63% of total cases, followed by crown damage (23%), buttress damage 10%, broken stem 2%, and bark damage 2% (Figure 3).



**Figure 2.** The relationship between felling intensity and forest opening analyzed using regression analysis



**Figure 3.** Type of tree damage as a result of tree felling



**Figure 4.** Number of seedling saplings and poles before and after harvesting

**Table 1.** Species, family, and vernacular name of the trees in all sample plots

Species	Family	Vernacular name
<i>Cinnamomum cuspidatum</i>	Lauraceae	Akar lawang
<i>Diospyros</i> sp.	Ebenaceae	Arang
<i>Shorea laevis</i>	Dipterocarpaceae	Bengkirai
<i>Duabanga moluccana</i>	Lythraceae	Binuang laki
<i>Durio zibethinus</i>	Malvaceae	Durian
<i>Ficus</i> sp.	Moraceae	Ficus
<i>Hopea</i> sp.	Dipterocarpaceae	Hopea
<i>Anthocephalus cadamba</i>	Rubiaceae	Jabon
<i>Dyera costulata</i>	Apocynaceae	Jelutung
<i>Dryobalanops lanceolata</i>	Dipterocarpaceae	Kapur
<i>Endospermum diadenum</i>	Euphorbiaceae	Kayu raja
<i>Shorea javanica</i>	Dipterocarpaceae	Meranti putih
<i>Koompassia malaccensis</i>	Fabaceae	Kempas
<i>Canarium commune</i>	Burseraceae	Kenari
<i>Dialium platysepalum</i>	Fabaceae	KerANJI
<i>Shorea palembanica</i>	Dipterocarpaceae	Majau
<i>Macaranga</i> sp.	Euphorbiaceae	Makaranga
<i>Shorea acuminatissima</i>	Dipterocarpaceae	Meranti kuning
<i>Garcinia mangostana</i>	Clusiaceae	Manggis
<i>Koompassia excelsa</i>	Fabaceae	Menngeris
<i>Litsea</i> spp	Lauraceae	Medang
<i>Shorea johorensis</i>	Dipterocarpaceae	Meranti merah
<i>Shorea parvifolia</i>	Dipterocarpaceae	Meranti merah
<i>Knema laurina</i>	Myristicaceae	Mendarahan
<i>Palaquium</i> sp.	Sapotaceae	Nyatoh
<i>Elasteriospermum tapos</i>	Euphorbiaceae	Pala
<i>Parkia speciosa</i>	Fabaceae	Petai
<i>Polyalthia glauca</i>	Annonaceae	Pisang-pisang
<i>Nephelium mutabile</i>	Sapindaceae	Rambutan
<i>Gluta aptera</i>	Anacardiaceae	Rengas
<i>Vatica</i> sp.	Dipterocarpaceae	Resak
<i>Macaranga hypoleuca</i>	Euphorbiaceae	Sedaman
<i>Scaphium macropodum</i>	Malvaceae	Semangkok
<i>Shorea pinanga</i>	Dipterocarpaceae	Tengkawang
<i>Helicteres isora</i>	Malvaceae	Ulas
<i>Eusideroxylon zwageri</i>	Lauraceae	Ulin
<i>Camnosperma</i> sp.	Anacardiaceae	Terentang
<i>Artocarpus odoratissimus</i>	Moraceae	Terap

**Table 2.** Indices of diversity and evenness before and after timber harvesting

Growth stage	Diversity Index (H')		Evenness Index (e')	
	Before harvesting	After harvesting	Before harvesting	After harvesting
Tree	2.84	2.84	0.82	0.82
Pole	2.88	2.85	0.87	0.87
Sapling	3.02	2.98	0.81	0.82
Seedling	2.65	2.64	0.77	0.78

**Table 3.** Stand density, felling intensity, stand damage, percentage of stand damage, and percentage of the forest opening

Plot	Stand density (trees/ha)	Felling intensity (trees/ha)	Stand damage (trees/ha)	Percentage of stand damage (%)	Percentage of forest opening (%)
1	80	3	11	14.1	11.22
2	69	4	6	9.2	9.11
3	60	9	10	19.6	17.89
4	48	6	7	16.7	23.74
5	71	8	13	20.6	22.2
6	101	10	20	22	25.5
7	59	5	9	17	15.02
8	52	7	9	20	24.61
9	37	6	6	19.4	15.78
10	42	7	7	20	13.36
Average	61.9	6.5	9.7	17.8	19.76

Natural regeneration in the form of vegetation at the younger stages, such as seedlings, saplings and poles, was damaged or died caused of harvesting activities. Before harvesting, the number of seedlings was 35,250 seedlings/hectare, and it decreased to 27,400 seedlings/hectare after harvesting (Figure 4). It means that the seedling mortality was 22.3%. While saplings decreased from 3872 saplings/hectare before harvesting to 3208 saplings/hectare after harvesting, the equivalent of sapling mortality of 17.1%. Poles also suffered damage in which before harvesting, the poles amounted to 248 poles/hectare, and reduced to 226 poles/hectare after harvesting (8.8% reduction).

## Discussion

The value of H' can be used to determine the effect of disturbance on the environment or the stages of succession and stability of the plant community in a location (Odum 1975). In our study, the diversity index (H') before and after harvesting showed moderate diversity (2-3) at all growth levels. The result of analysis on the diversity index indicates that the species diversity before and after timber harvesting remained relatively the same. Timber harvesting of natural forests in Indonesia extracts only commercial trees. In this location, only three species of the Dipterocarpaceae family were logged. The logged trees had a diameter of more than 50 cm, and there were many remaining trees with a diameter smaller than 50 cm. The result of the study is in line with the research by Hayward et al. 2021 that they found no significant effect of logging on tree species richness or diversity indices in Borneo.

The evenness index (e') is used to determine the stability of the species in the community. The greater the value of e', the stronger the stability of the vegetation community. The value of  $e' = 0 < 0.3$  indicates low

stability, while e' between 0.3 and 0.6 indicates moderate and the value of  $e' > 0.6$  indicates high stability (Magurran 2004). Table 2 shows the value of e' for all growth stages was  $> 0.6$ , indicating that the level of stability of the diversity of species was high. This result suggests that species sustainability at all growth levels tends to be maintained (Jost 2010). Some research in the tropical region showed a high level of stability of species diversity (Yano et al. 2021; Rahayu et al. 2022).

The stand damage caused by timber felling had a positive relationship with felling intensity. In this research, the percentage of stand damage was 17.8 % (Table 3). It was lower than stand damage in Central Kalimantan dan West Sumatra with 27.8% and 22.4%, respectively. The percentage of stand damage increases in line with the increase in felling intensity (Matangaran et al. 2019a). The level of stand damage affects forest recovery after disturbance (Matangaran and Rishadi 2014; Piponiot et al. 2018; Hayward et al. 2021; Han et al. 2021).

Reduced Impact Logging (RIL) requires several procedures to reduce the environmental damage caused by timber harvesting. The RIL technique limits the number of trees that can be felled per hectare (felling intensity), significantly reducing stand damage. In this research, we found that an increase in trees harvested per hectare will increase the gap in opening a forest, as shown in the regression of Figure 2. The crown of the tree will be more open, and the increase of skid trail by the bulldozer movement. Several studies have reported on the effect of felling intensity on vegetation cover and biodiversity (Costantini et al. 2016; França et al. 2017; Burivalova et al. 2021). In implementing RIL, a logging plan is required prior to logging. Topographic and tree mapping are essential when planning a skidding road plan. Besides minimizing stand damage, good planning can also reduce

soil damage, such as soil compaction due to bulldozer movement for skidding logs (Lefeuvre et al. 2022).

Forest opening in this study was limited to the felling gap and skid trail. A study in Bolivia showed that 25% of the damage caused in the form of canopy openings was due to tree felling, and 25% of the ground area was damaged by skid trails, logging roads, and landing sites (Jackson et al. 2002). In this research, the percentage of forest opening area was 19.76 % (Table 3), which was lower than the research in Bolivia (Jackson et al. 2002). The lower result in our study was likely due to the calculation of forest opening only accounting for the felling gap and skid trail, and did not include logging road and log landing. Similar to what is applied in the planning stage, planning for tree harvesting and the skidding trail are required in the implementation of RIL. Several studies have shown that this is a critical consideration in logging to mitigate the ecological consequences on the natural environment (Pereira et al. 2002; Okuda et al. 2019; Antobre et al. 2021; Shabani et al. 2021; Trýzna et al. 2021).

In this research, five types of tree damage occurred caused by timber felling activity (Figure 3). This result is lower compared with other research in Central Kalimantan in which there were six types of tree damage (Matangaran et al. 2019a). In this research, we did not find uprooted trees which 8% occurred in Central Kalimantan. In East Kalimantan, the research found that the type of tree damage was crown injury, broken wood, and uprooting (Iskandar et al. 2006). The crown injury was the most frequent damage found in Para Brazil (Pereira et al. 2002).

Several seedlings, saplings, and poles died as an impact of harvesting activities (Figure 4). Decreased natural regenerations due to fallen trees were worsened by the impact of bulldozers when skidding the logs. Previous studies showed that timber felling and skidding reduce the number of seedlings, saplings and poles in the natural tropical forest, such as in eastern Amazon Brazil (Bezerra et al. 2021), Kenya (Maua et al. 2020), Northern Thailand (Sangsupan et al. 2021), Bolivia (Park et al. 2005), Central Kalimantan Indonesia (Blackham et al. 2014), and India (Subashree et al. 2021). Also, the mortality of commercial trees by logging was reported in eastern Amazonia (Dionisio et al. 2017).

Felling and skidding logs in tropical forests generally disturb forest stands and other environmental elements (Diatin et al. 2018; Lestari et al. 2019). It changes stand structure (Mohammed et al. 2021) and natural regeneration (Snook et al. 2021; Pozner et al. 2022; Sullivan et al. 2022), and impacts the diversity of mammals and birds and the evenness and diversity of the species of a forest stand (Wijedasa et al. 2020; Mohanta et al. 2021). Therefore, it is crucial to set aside a protected area in the production forest as well as control the logging, especially the felling intensity of the tropical forest (Edwards et al. 2014; Ali et al. 2022; Liu et al. 2022).

In conclusion, biodiversity indicators in terms of diversity and evenness index before and after harvesting were nearly identical. This is understandable since on average, the felling intensity was considered low with only 6.5 trees/hectare, so stand damage and mortality of the

trees were not high. The percentage of stand damage was also lower than in other harvesting locations in Kalimantan and Sumatra. The forest opening from the felling gap and skid trail was only 19.76%, which was also lower than research in other countries. The number of seedlings, samplings and poles as indicators of natural regenerations decreased as the collateral impacts were caused by timber felling. There was a strong positive relationship between felling intensity and forest opening in which the higher the felling intensity, the higher forest opening. The findings of this study imply that limiting trees logged per hectare, for example, in this area maximum of 10 trees per hectare, can minimize logging damage and forest opening with a slight impact on tree species diversity and natural regeneration.

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