Pattern of forest biomass recovery and biodiversity loss after reduced impact logging in East Kalimantan

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Abstract. Climate change substantially impacts sustainable ecosystem management, seeking to maintain the maximum amount of biomass and control biodiversity loss. Reduced impact logging (RIL) is a means to reduce the impact of biomass and biodiversity loss on natural production. This practice makes an important contribution to climate change mitigation and adaptation. This study aimed to determine the variation pattern of biomass recovery and biodiversity loss on natural forest stands after using the RIL technique. The approach to assessing the pattern was based on measuring growth patterns and quantitative ecological parameters on stands. The value was constructed based on STREK plots data in the Labanan forest. The total plot was 48 ha with 4 different treatments, using 28 years of data measurements. The biomass recovery values pattern is based on stand structure pattern, basal area, volume and aboveground biomass values. The biodiversity loss indicated by quantitative ecological values included a heterogeneity index, richness index, and similarity index. Fluctuations on stand structure changes followed lognormal curves. This study demonstrates the importance of the RIL technique in maintaining existing stored biomass in standing stock and allowing 99 % recovery 27 years after logging. This technique could curtail biodiversity loss as indicated by maintaining the high heterogeneity and richness indices of species, but the similarity to the primary forest’s initial conditions will reach 60–70 %.

1. Introduction

Forest ecosystem management views are very close to the issue of climate change. The rate of forest degradation was one of the largest contributors to emissions in the world. Various mitigation and adaptation efforts in the field of forest management to minimize forest and environmental damage. Especially as a result of forest exploitation activities in natural production forests. The concept of sustainability is directed to consider more balanced various aspects of production, ecology and the local community as social aspects. In connection with this issue, the exploitation of natural production forests includes at least two main things: the stored biomass and biodiversity loss. Large-scale land use and land cover changes can substantially impact natural ecosystems, such as loss of biodiversity and carbon [1]. Various efforts and improvements are needed in natural forest logging techniques to maintain the maximum amount of stored biomass and control the biodiversity loss from the forest ecosystem.

Study of forest stand recovery in which approaches to comparing with the prior condition of forest or primary forest can be seen from several factors. The different characteristics of natural forest is a factor of variety the stand recovery or even the ecosystem. It is indicated by many quantitative parameters such as density, basal area, stand structure, diversity of species and also the ecological aspect [2][3][4]. Some studies in other countries consistently show the main cause of forest degradation in
tropical forests is the lack of logging planned [5]. Study of using Reduced Impact Logging (RIL) techniques in Eastern Amazon will reduce residual standing damage by up to 30-50% compared to conventional logging [6]. RIL is an effort to minimize the impact of stand damage included the seedling. Even this technique could be able to maintain natural forest biodiversity on natural production forest. This makes an important contribution to climate change mitigation and adaptation.

Growth pattern of stands is a result of genetic traits and their environment [7][8]. Cause the difference of species composition in vegetation, the individual tree's growth response will form the different the stand growth [9][10][11]. After logging, management of natural forests plays an important role in ensuring the direction of forest growth stands towards sustainable yields, especially on natural production forest [5][12]. The recovery assessment study of natural forest stands after logging indicated has two important aspects that could be considering [13][14]. Which is the important indicator by the productivity and conservation ecology parameters.

The study was conducted on secondary lowland rainforest conditions after logging with initial primary forest. This aimed to determine the variation pattern of biomass recovery and biodiversity loss on natural forest stands after RIL technique. The approach to assessing the pattern based on recovery pattern of biomass and quantitative ecological parameters on stands.

2. Materials and methods

2.1. Study sites

The study was carried out on the Silvicultural Technique for the Regeneration of Logged Over Forest in East Kalimantan (STREK) plot in the Labanan Forest Research Station. It is located in Labanan Village, Berau Regency, East Kalimantan, between 117° 10’ 22" and 117 ° 15’ 35" E and 1° 52’ 43" and 1° 57’ 34” N.

| Treatments in specific of STREK plots |
|--------------------------------------|
| Plots                                 | Treatments                          |
| 1, 4, 10                              | Primary Forest (control) (PF)       |
| 2, 3, 12                              | Reduced Impact Logging dbh ≥ 50 cm (RIL 50) |
| 5, 6, 7                               | Reduced Impact Logging dbh ≥ 60 cm (RIL 60) |
| 8, 9, 11                              | Conventional dbh ≥ 60 cm (CNV)      |

The research plot is a permanent plot established in 1990/1991. The plot was initially a primary forest. Logging was conducted in 1991. Stand observations were made every 2 years. Portions of the STREK plots describe in Table 1 were subjected to the following treatments:

a) Reduced Impact Logging 50 cm (RIL 50) is a logging technique with a diameter at breast height (dbh) limit of 50 cm, minimizing damage to existing stands by planning tree positions and skid trail maps to monitor the felling.

b) Reduced Impact Logging 60 cm (RIL 60) is a logging technique with a diameter at breast height (dbh) limit of 60 cm, minimizing damage to existing stands by planning tree positions and skid trail maps to monitor the felling.

c) Conventional technique (CNV) is a logging technique with a dbh limit of 60 cm based on the logger’s experience (no planning maps or control).

d) Primary forest (control).

2.2. Data collection

A research plot was 200 m x 200 m (4 ha) divided into 4 subplots of 100 m x 100 m (1 ha). The research plots represented the 4 variations of logged-over natural forests and primary forest as control. 12 plots with a total area of research plots of 48 ha. Stand data collection was based on field inventory conducted by census for all tree species with a dbh limit of 10 cm. Design of each plot describes in Figure 1.
Figure 1. Design of research plot

Stand data collection was based on field inventory activities carried out by census in a research plot for all tree species with a diameter limit of 10 cm. This study uses measurement data from 1990 - 2018 (observations from before logging/primary condition to 27 years after logging).

2.3. Data analysis
The pattern of biomass recovery values was based on stand structure pattern, basal area (ba), volume (vol) and aboveground biomass (AGB) values using data collected 1990–2018. The biodiversity loss was indicated by the heterogeneity index (H’), richness index (R1), and similarity index (SI) using data collected from 1990–2014.

The stand structure model is prepared based on the selected model published previously [15].

Lognormal distribution family:

\[ f(x) = \frac{1}{x \delta \sqrt{2 \pi}} \exp\left[-\frac{1}{2} \left(\ln x - \mu / \delta\right)^2\right] I_{(0, \infty)}(x) \]  

(1)

The model used for tree density (N) and stand basal area (G):

\[ N_{1-2} = \left( \int_{x_1}^{x_2} f(x) dx \right) N \]  

(2)

in which \( N_{1-2} \) = estimated tree density in the diameter interval \( x_1 \) to \( x_2 \); \( N \) = total stand density from observations; \( f(x) \) = density function of the selected distribution family

\[ G_i = \frac{1}{10^4} \times (\pi / 4) \times \left( x_i \right)^2 N_i \text{im}^2/\text{ha} \]  

(3)

in which \( G_i \) = stand basal area of diameter class \( i \); \( x_i \) = tree mean diameter of diameter class \( i \);

\( N_i \) = stand density of diameter class \( i \)

\[ B_a = \sum \left( \frac{\pi}{4} \times d^2 \right) \]  

(4)

in which \( B_a \) = basal area of stand(m2/ha); \( d \) = diameter; \( \pi \) = constant (3.1415)

\[ \text{Log Vol} = -3.6987519 + 2.3925507 \log (d) \]  

(5)

in which \( \text{Vol} \) = volume of trees (m3.ha-1); \( d \) = diameter

\[ \text{AGB} = \text{Vol tegakan} \times \text{BCEF} \]  

(6)
in which AGB = stand above ground biomass (ton.ha\(^{-1}\)) [16]; Vol = stand volume (m\(^3\).ha\(^{-1}\)); BCEF = biomass conversion and expansion factor (based on IPCC 2006)

\[ H' = -\sum_{i=1}^{n} \left( \frac{ni}{N} \right) \log \left( \frac{ni}{N} \right) \]  

(7)

in which \( H' \) = species heterogeneity index; \( ni \) = Number of species–i; \( N \) = total number of all species

\[ R1 = \frac{S-1}{\ln(n)} \]  

(8)

in which \( R1 \) = richness Margallef index; \( S \) = number of species; \( n \) = number of individuals of all species

\[ IS = \frac{2w}{a+b} \times 100\% \]  

(9)

in which \( IS \) = similarity index; \( w \) = quantitative value from the same species on community a & b; \( a \) = quantitative value [density & basal area] on vegetation a; \( b \) = quantitative value [density & basal area] on vegetation b.

3. Results and discussion

3.1. Recovery of stand structure after logging

Figure 2. Comparison of probability density functions and stand structure based on a lognormal model for all species after logging and in the primary forest (Source: primary data and Susanty [3])
Based on the selected distribution function, which is lognormal, then logged-over stands of 5, 9 and 27 years and in primary forest. They have a stand population that forms a stand structure distribution pattern based on stand density following the de Lio Court curve pattern or inverted J curve. Meanwhile, the stand structure based on the stand's basal area will have the highest peak value in the diameter class of 20-40 cm, which is the standing stock of stand after logging (Figure 2).

At the young age of harvest (5 years after felling), the curve tends to fall for all stand dimensions. In this felling with a diameter limit of 50 cm to the depths, a decrease in stand density also shifts the regeneration curve. This indicates that the impact of logging that occurs is removing the felled trees from the forest and kills regeneration due to the clearing and preparation of skid trails or the logging itself. Both in terms of stand density and basal area, the older the harvesting age, the closer to the initial conditions before logging or the primary forest condition. At 27 years after logging, in the regeneration class with a 10-30 cm diameter, both values are close to the values in primary forest conditions. In other studies, the acceleration was done to repair and increase stand productivity [17]. In some cases, the general stand manipulation attempts to increase the stand productivity by stand arrangement [11][18].

3.2. Pattern of forest biomass recovery after logging

The review of forest biomass restoration changes can be described based on the dynamics of the restoration of basal area, volume and aboveground biomass values over natural forests' cutting life. The results of this study used a BCEF value of 0.95 for all sampling plots, according to the IPCC guidelines (2006) in Krisnawati et al [16] for volumes > 200 m³.ha⁻¹ in tropical natural forests. The calculation results obtained for these three parameters are presented in Figure 3-5, respectively.

Based on basal area values at 1 year after logging, the clearing (opening gap) intensity was highest in conventional techniques (30%), followed by RIL 50 (26%) and RIL 60 (21%). This shows that controlled logging techniques can withstand the reduction in standing forest cover due to this cutting. Meanwhile, based on the value of the volume lost immediately after logging, it shows that the highest felling intensity is by conventional techniques at 80 m³.ha⁻¹ (25% of the initial potential). Whereas the RIL technique tends to be similar, namely 69 m³.ha⁻¹ (20% of the initial potential) in RIL 50 and 64 m³.ha⁻¹ (18% of the initial potential) in RIL 60.

![Figure 3. Recovery of stand basal area after logging](image-url)
The recovery of standing forest AGB (Above Ground Biomass) after logging will occur after logging and close to the pre-harvest condition at 9 years after harvesting for the three different cutting techniques. The volume achieved from restoring the stands was 89 - 95% of the original volume before felling. Moreover, after that, there is a slower dynamic for restoration of stands or slow growth. This is thought to stand that require maintenance or thinning because the density is high enough but slows down the individual trees' growth. So that at the age of 27, after logging, the response to forest stand AGB recovery will be different. After logging using the RIL 50 technique, the standing forest will increase to 99% from the baseline, while the conventional technique (91%) and RIL 60 (85%) tend to decline from the 9th year after logging. Study on West Kutai and Mahakam Ulu in East Kalimantan indicated that
between 1990 and 2009 there is change resulting in a mean AGB decline from about 280 to 230 ton.ha\(^{-1}\) which is about 18\% [1].

Variations in initial conditions and a history of intensity of forest destruction greatly affect recovery [14]. Several environmental factors were the most significant in determining differences in vegetation characteristics and recovery in the plots tested [19]. Restoration of standing forests will continue over time [13], but the diversity of logged forests causes the length of recovery will vary, depending on widespread forest degradation and environmental transport capacity.

(Source: produces from data on Susanty [15])

**Figure 6.** Biodiversity loss value based on ecological quantitative index
3.3. Biodiversity loss after logging

Biodiversity loss assessment occurs in the forest after logging by comparing the condition of species diversity, level of species richness and species similarity in the vegetation or forest ecosystem in each forest condition. To see changes in the level of stand stability as indicated by the quantitative ecological value. Based on Krebs’ provisions, stands with a higher diversity index value will show a higher level of stability. Whereas for the criteria of species richness using Magguran 1988, which is high if R1 > 5.0, moderate if R1 ranges between 3.5-5.0 and low if R1 < 3.5.

Figure 6 shows that in the logged-over forest condition in the selective logging system, it will maintain biodiversity in the forest vegetation. The species diversity index shows that all sampling plots have a high level of diversity. Relatively comparatively, natural forest after 23 years still has lower diversity than that of primary forest. Based on magguran criteria, the three logging techniques maintained high species richness in each study plot (R1 > 5). It is important to understand that after logging, pioneer species will appear and a transition to climax forest will be more diverse than the primary conditions. The similarity in the composition of forest vegetation constituents’ types shows that the forest 23 years after logging has a similarity index of 60-70%. Research on several types of tropical lowland forests in Vietnam showed a lower level of biodiversity (1.07 - 1.45) and lower species richness (3.52-6.12) compared than this study result [20].

The response on natural forest after logging will vary even on the same aged stand after logging [4][13][14]. By naturally, forest after logging will be recovered with the succession stage of vegetation. There will be an increase in species richness and diversity, especially in open areas. In tropical forest recovery, composition species’ difference in the early stages after disturbance [8][13]. The survival of the species of trees also varies. It’s depending on species characteristic and genetic spread form [10].

4. Conclusion

After logging, forests will recover through succession naturally based on typical carrying capacity and level of damage as the function of time. Fluctuations in stand structure changes follow lognormal curves. This study showed the RIL technique’s effects on maintaining the existing amount of stored biomass in standing stock and then recovering 99% at 27 years after logging. This technique could also control biodiversity loss, as indicated by the high heterogeneity and richness index of species, but the similarity was only 60–70% of the initial condition or primary forest.

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