Study of recovery rates of natural forest stands after logging in East Kalimantan

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Abstract. Recovery assessment of forest conditions after disruption, especially after logging, tends to vary depending on the aspects viewed and who judges. Forests after logging will recover through succession naturally based on the characteristics of typical carrying capacity and level of damage to the function of time. The purpose of this study is to determine the variation of recovery rates of natural forest stands after logging in different conditions and vary age after logging. The approach to assessing the recovery rate of natural forest stands after logging based on the biometric characteristic performance formulation values, as mentioned as BCP value. The BCP value was constructed and compiled based on the results of studies on permanent STREK plots in KHDTK Labanan. The BCP value is based on four crucial variables, which included: stand density, periodic increments of basal area, evenness index and species abundance. Forest stand conditions on age 1-23 years after logging, the range of BCP values are 11.99-23.48 shows a still low recovery rate. The implications of the BCP value on its four constituent components provide direction for silvicultural treatment needed in order to accelerate the increase of forest stand productivity and ecological review of its constituent biodiversity.

1. Introduction
Stand recovery is the condition of forest stands after harvesting that is close to the condition before the forest is managed (primary forest). This condition can be seen from several factors such as density, number and diversity of species, species composition and diversity, stand structure [1], ecological processes of stand structure and soil mass density [2], and formulation of static and dynamic forest stand dimensions [3]. Studies in Africa, Amazonia, and Southeast Asia clearly and consistently show the leading cause of forest degradation in tropical forests is the lack of logging plan. Logging with reduced-impact logging techniques will reduce residual standing damage by up to 30-50% compared to conventional logging [4]. The length of time after disturbance to the forest is assumed to be the best estimate of forest recovery seen from the characteristics of forest structures in the succession process.

At the scale of forest exploitation, forest restoration has a narrow understanding, that is as the return of potential for commercial types of stands in the forest area. Understanding and assessment of recovery indicators on natural production forests are still partial and diverse. It has not yet been considered the process of interaction of eco-physiological conditions as a unity of factors that make up...
the desired natural forest productivity. A partial review of forest restoration assessment [5, 2, 3] indicates that a form of recovery assessment should be formulated that includes multi aspects of both stand productivity, biodiversity conservation and forest health or quality. The need and demand for a multi-faceted and measurable model of forest recovery will be the basis for determining appropriate silvicultural measures in sustainable forest management.

In 2015 a basic formulation was formulated for the assessment of restoration of natural forest stands after logging based on a study on the 25 years STREK plot after logging [6, 7]. These variables are structured as an essential indicator in the assessment by the productivity and ecology of conservation of natural forest stands after logging. The result of the analysis showed that the condition of the primary forest has a more complex structure compared to logged forest and forest after thinning. The characteristic and biometric performance of mixed Dipterocarpaceae forest are the assessment of the closeness of the forest stand to primary forest conditions for supporting the assessment. The forest development paradigm used to approximate the existing natural forest conditions area (close to the natural forest).

This study aims to describe the condition of the variation in the level of natural forest stands after logging recovery based on site conditions and age of forest felling. The recovery rate assessment approach is based on the performance value of biometric characteristics formulation as an essential quantitative dimension both of productivity and conservation aspect.

2. Methodology
2.1. Study site
The research was carried out at two concession locations in East Kalimantan, i.e., PT. Triwira Asta Bharata is an ex area of PT. East Kalimantan Timber Industries (PT. EKTI) (next mention as TAB-Melak) located on Kutai Barat Regency and PT. Segara Indochem (next mention as SI-Sangkulirang) on Sangkulirang, Kutai Timur Regency.

Geographically, PT. TAB-Melak is located between 0° 05'- 0° 14' South Latitude and 115° 32'-115° 57' East Longitude. Based on the division of government administration, the work area of PT. Triwira Astha Bharata belongs to Melak District, Long Iram District, West Kutai Regency, East Kalimantan Province. Based on the division of forested areas, this area belongs to the Senduru concession resort area, Long Iram - Kutai Barat, East Kalimantan Provincial, which included in the Forest Management Unit (FMU) Mook Manarr Bulan.

PT. SI-Sangkulirang is located between 0°23' 00" - 1°40'00" North Latitude and 117° 28' 00" - 117° 52' 00" East Longitude geographically. Based on the division of government administration, the work area is included in the Karangan District, East Kutai District, East Kalimantan Province. Based on the division of forested areas, this area belongs to the Mahesi River Forest Group, which is included in FMU Berau Barat.

Temporary sampling plots built as six plots (size 100 x 100 m [1 ha] per each plot) on three different age stands after logging, which each location as follows Tables 1 and 2 below.

Table 1. Temporary sampling plots on PT. Triwira Asta Bharata, Melak (TAB-Melak).

| Years after logging | Coordinate          |
|---------------------|---------------------|
| 23 years            | 50 N 0° 02' 17.4"   |
|                     | E 115° 36' 16.8"    |
| 9 years             | 50 N 0° 08' 24.0"   |
|                     | E 115° 41' 8.2"     |
| 4 years             | 50 N 0° 08' 12.0"   |
|                     | E 115° 39' 13.8"    |
Table 2. Temporary sampling plots on PT. Segara Indochem (SI-Sangkulirang).

| Years after logging | Coordinate       |
|---------------------|------------------|
| 6 years             | 50 N 01° 34’ 55.7” N  |
|                     | E 117° 37’ 51.1” E  |
| 3 years             | 50 N 01° 15’ 22.3” N  |
|                     | E 117° 27’ 14.0” E  |
| 1 years             | 50 N 01° 30’ 56.7” N  |
|                     | E 117° 44’ 10.1” E  |

Assessment of the recovery rates of logged-over forest stands was conducted based on typical ecological characteristics (Table 3).

Table 3. Forest typology based on ecological characteristics.

| Ecological characteristics | TAB-Melak                          | SI-Sangkulirang                        |
|----------------------------|------------------------------------|----------------------------------------|
| Forest type                | Low land tropical rain forest      | Low land tropical rain forest          |
| Elevation (m above the sea level) | 50 – 1,020 m                      | 100 – 600 m                            |
| Topography                 | Flat – Rather steep                | Slope – Steep Fragmentation level      |
| Connected Safe             | Connected Biological safety        | Safe                                   |
| Physical safety            | Safe                               | Vulnerable                             |
| Ecological type            | Safe biologic – Safe physic        | Safe biologic – vulnerable physic      |

2.2. Data collection

The temporary and permanent sampling plots were set up twelve plots, which at aged least two years. Variation of natural forests after logging was determined by covering three different logged-over periods that were categorized as young (<5 years), medium (5-15 years) and old (> 15 years). The plots design that built was 100 x 100 m, with the size of the subplot is 20 x 20 m. The residual tree stands with at least 10 cm dbh were measured by census inventory method in the plots.

2.3. Data analysis

Assessment of restoration of natural forest stands after logging based on several important stand parameters including:

\[
\text{Density (stems. ha}^{-1}) = \text{Number of trees .plot area}^{-1} \\
\text{Ba} = \sum (\frac{1}{4} \cdot \pi \cdot d^2) .\text{plot area}^{-1} \\
\text{Ba} = \text{basal area of stand} (m^2/ha); d = \text{diameter}; \pi = \text{constant} (3.1415) \\
\text{rBa}_i = \text{Periodic annual increment of stands} (m^2 \ ha^{-1} \ 2\text{years}^{-1}) \ [8, 9]; \text{ba}_0 = \text{basal area on measurement} \ t (m^2 \ ha^{-1}); \text{ba}_1 = \text{basal area on measurement} \ t+ \ 2\text{years} (m^2 \ ha^{-1}) \\
\text{H} = -\sum_{i=1}^{n} \left( \frac{n_i}{N} \right) \log \left( \frac{n_i}{N} \right) \\
\text{H} = \text{Species Heterogeneity Index (Shanon dan Wiener)} \ [10]; n_i = \text{Number of species} –i; N = \text{Total number of all species}
\]
\( N_1 = e^{H} \)  
\( H' = \text{Species Heterogeneity Index} \)  
\( E = \frac{H'}{\ln(S)} \)  
\( E = \text{Evenness Index Pielou} \) \( J' \) (Magurran 1988) [10]; \( H' = \text{Species Heterogeneity Index} \); \( S = \text{Number of species} \)

The formulation for assessing the restoration rates of natural forest stands after logging was carried out using the BCP value approach which constructed based on the STREK plot time-series data for 25 years [6] with the following formula:

\[
\text{BCP Value} = 0.77 \text{Bd} + 0.74 \text{rBd} + 0.83 \text{E} + 0.80 \text{N1} \tag{7}
\]

**BCP Value = recovery rates of stand after logging; Bd = stand basal area (m}^2\text{.ha}^{-1}); rBd = \text{Periodic annual increment of stands} (m}^2\text{.ha}^{-1} \text{years}^{-1}); E = \text{Evenness Index Pielou}; N1 = \text{Species abundance}**.

### 3. Result and Discussion

#### 3.1. Important variables of stand recovery assessment

This study using the assessment formula of forest stand recovery after logging that build in 2013-2016. It is based on four important parameters of recovery were obtained, namely: density, baseline, basal area increment, the abundance of species and species density. These variables are arranged as important indicators in assessing the level of productivity and ecology conservation of natural forest stands after logging. The arranged in the following formula \( \text{BCP} = 0.77 \text{Ba} + 0.74 \text{rBa} + 0.83 \text{E} + 0.80 \text{N1} \). This formulation is hereinafter referred to as Biometric Characteristics Performance (BCP) [6, 7]. The recapitulation of important variables in each plot is presented in Table 4 below.

**Table 4.** The important variable of the quantitative dimension of the logged over stand.

| Location | Years after logging | K  | BD  | J   | \( H' \) | N1  | E   |
|----------|---------------------|----|-----|-----|----------|-----|-----|
| TAB-Melak| YAL 4 (1)           | 282| 24.59| 27  | 1.09     | 2.99| 0.27|
|          | YAL 4 (2)           | 373| 20.34| 26  | 1.08     | 2.95| 0.27|
|          | YAL 9 (1)           | 475| 22.00| 31  | 1.16     | 3.20| 0.29|
|          | YAL 9 (2)           | 348| 14.11| 36  | 1.23     | 3.44| 0.31|
|          | YAL 23 (1)          | 462| 15.94| 21  | 1.19     | 3.27| 0.30|
|          | YAL 23 (2)          | 348| 16.99| 44  | 1.32     | 3.74| 0.33|
| SI       | YAL 1 (1)           | 319| 20.34| 30  | 0.99     | 2.68| 0.25|
| Sangkuliang| YAL 1 (2)          | 249| 14.74| 20  | 1.05     | 2.85| 0.26|
|          | YAL 3 (1)           | 290| 12.58| 22  | 0.88     | 2.40| 0.22|
|          | YAL 3 (2)           | 291| 16.81| 23  | 0.89     | 2.43| 0.22|
|          | YAL (1)             | 365| 19.27| 29  | 1.07     | 2.93| 0.27|
|          | YAL 6 (2)           | 274| 17.61| 25  | 1.03     | 2.81| 0.26|

Notes: YAL \( i \) = logged over forest stand at aged \( i \) years after logging;  
K = stand density (number of stems.ha\(^{-1}\));  
BA = stand basal area (m}^2\text{.ha}^{-1});  
J = number of species;  
H’ = Heterogeneity/Diversity Index (Shannon & Wiener);  
N1 = species abundance;  
E = Index of evenness (Pielou J)
The stand density of sampling plots in both concessions has a lower range compared to the referred model plot conditions (plot STREK amounting to 461 – 647 stems ha\(^{-1}\) with an average of 531 stems ha\(^{-1}\)) [7]. Only at the location of the TAB-Melak logged-over forest stand, the density conditions close to the density value in the STREK condition. This indicated that the range of density values from the sampling plots that built is wide for the field test [11]. There are no trends between aged years after logging with stand density of residual stands.

The basal area of stands at two concession sampling ranged from 12.58 - 24.59 m\(^2\) ha\(^{-1}\). Generally, this value is still on the range of basal area of logged-over forest stands in East Kalimantan. The value of the basal area of the stand is lower than the STREK plot, which is equal to 19.35-31.84 m\(^2\) ha\(^{-1}\) with an average of 23.68 m\(^2\) ha\(^{-1}\). In general, from a review of the results of previous studies, the sampling plots built have stand density values that are still within the range of the existing density values for logged-over forests in Kalimantan [5, 2, 12].

The periodic annual increment value of stand as a dynamic dimension based on the analysis of permanent sample plots (time series data). In both concession sampling, both at TAB-Melak and SI-Sangkulirang obtained supporting data from the measurement of permanent plots on the concession area. The range of basal area increment values in the TAB-Melak ranges from 0.29 -2.60 m\(^2\) ha\(^{-1}\) yr\(^{-1}\), while at SI-Sangkulirang ranges from 0.48 - 2.36 m\(^2\) ha\(^{-1}\) yr\(^{-1}\). Both value of this increment resembling with the conditions on the STREK plot with conventional logging techniques, which range from 0.27-2.10 m\(^2\) ha\(^{-1}\) yr\(^{-1}\) [7].

The recapitulation of species numbers for each measurement plots showed that there is a difference in the species abundance on forest stand composition after logging. The differences in the assessment of species numbers that occur are also possible because of differences in the species details identification at the genus or species level. This is strongly influenced by the availability and ability of type identifiers (botanists) at the time.

The species heterogeneity index illustrates the level of diversity of constituent vegetation in a forest community. The number of species and individual evenness indicated by the magnitude of the value of $H'$. Based on the Magguran classification indicates for all sampling plots in forest stands after logging have a low species diversity index ($H' <1.5$). Relatively the species diversity index in logged-over forests has a diversity of species which is still low to moderate, compared to some logged-over forest conditions in some Kalimantan regions [13]. The recovery as time function after logging has not shown by the pattern of species diversity index change [6]. Change of floristic composition will occur after disturbance shortly. Until 25 years after logging by selective cutting in the Venezuelan forest, the species composition is quite adequate 91% [14].

The effect of selective cutting on forest stands on stand diversity will vary for each habitat [15]. In several studies, it was shown that the effect of selective logging did not significantly influence forest species diversity for 18-20 years after logging [15]. When compared to the condition of primary forests, 41-year-old logged-over forests have a lower level of species diversity. Stand after logging. There will be an increase in species richness and diversity, especially in open areas. In tropical forest recovery, the family composition in the early stages after the disturbance has differed from primary forest [16, 17]. The survival of the trees is also vary depending on species characteristic and genetic [18].

The evenness index shows the evenness level of abundant species of constituent vegetation in a forest community. The higher the value of E indicates the composition of species more evenly or not dominant in one or some species. Based on the evenness index according to Magurran classification, the criteria are: high if the E value is> 0.6, medium if the value of E ranges from 0.3 -0.6 and low if the value of E <0.3. Based on this classification, both concessions have moderate and low evenness. It means that the stand composition is scattered across in all species, but more likely to be dominant for certain species. Compared with the results in the STREK plot [6] where logged-over forests have an evenness value that increases up to the 5th year after logging, then decreases and tends to change. Evenness conditions in stands after logging up to 23 years are still lower than in primary forest conditions. So it is necessary to review the species composition for recovery not only by production perspective but also by the ecological view.
Figure 1. The tendency of recovery assessment by the important variables on forest stand after logging.

Remarks: LOAi = logged over forest stand at aged i years after logging;
K = stand density (number of stems ha\(^{-1}\));
BA = stand basal area (m\(^2\).ha\(^{-1}\));
J = number of species;
H' = Heterogeneity/Diversity Index (Shannon & Wiener);
N1 = species abundance;
E = Index of evenness (Pileou J)

3.2. Biometric Characteristic Performance (BCP) formulation value

Recovery rates by BCP value calculation, using two scenarios were scored as the first using the increment value from STREK plot analysis and the second using the increment value result by the local concession itself. The range of basal area increment values for TAB-Melak between 0.29-2.60 m\(^2\) ha\(^{-1}\).yr\(^{-1}\). While at SI-Sangkulirang concession is ranged between 0.48-2.36 m\(^2\) ha\(^{-1}\).yr\(^{-1}\).
While stand increment value on STREK plots with conventional logging techniques [7] is ranged between 0.27-2.10 m² ha⁻¹ yr⁻¹. This has implications that the forest stands after logging at two study location with a model stand having a similar range of increment or the growth rates. For applying recovery assessments, with two scenarios using the baseline scores that approximate the condition of logged-over natural forest.

Recovery rates values result indicated there is no tends between aged after logging and BCP value. The older age after logging does not always have a better recovery condition. BCP value is the ratio value of a stand of the logged-over forest to the primary forest condition. This result shows that for all stand after logging, having a low recovery below 25 (primary forest in the STREK plot as a comparison). The results of recovery rates by BCP value are followed in Table 5.

Table 5. Recovery assessment of natural logged over forest.

| Location       | Years after logging | Scenario 1 (m² ha⁻¹ th⁻¹) | Scenario 2 (m² ha⁻¹ th⁻¹) |
|----------------|---------------------|-----------------------------|-----------------------------|
|                |                     | rBa 0.27-2.10 (STREK)       | rBa 0.29-2.60 (PSP TAB- Melak) |
|                |                     | BCP low                     | BCP high                    | BCP low                     | BCP high                    |
| TAB- Melak     | YAL 4 (1)           | 21.75                       | 23.11                       | 21.77                       | 23.48                       |
|                | YAL 4 (2)           | 18.45                       | 19.80                       | 18.46                       | 20.17                       |
|                | YAL 9 (1)           | 19.94                       | 21.30                       | 19.96                       | 21.67                       |
|                | YAL 9 (2)           | 14.07                       | 15.42                       | 14.08                       | 15.79                       |
|                | YAL 23(1)           | 15.34                       | 16.69                       | 15.35                       | 17.06                       |
|                | YAL 23(2)           | 16.55                       | 17.90                       | 16.56                       | 18.27                       |
| SI- Sangkulirang | YAL 1 (1)           | 18.21                       | 19.57                       | 18.37                       | 19.76                       |
|                | YAL 1 (2)           | 14.05                       | 15.40                       | 14.21                       | 15.60                       |
|                | YAL 3 (1)           | 11.99                       | 13.34                       | 12.14                       | 13.53                       |
|                | YAL 3 (2)           | 15.27                       | 16.63                       | 15.43                       | 16.82                       |
|                | YAL 6 (1)           | 17.60                       | 18.96                       | 17.76                       | 19.15                       |
|                | YAL 6 (2)           | 16.22                       | 17.57                       | 16.38                       | 17.76                       |

Notes: YAL i = logged over forest stand at aged i years after logging;  
 rBA = periodic basal area increment (m² .ha⁻¹ yr⁻¹);  
PSP = permanent sample plots;  
BCP = Biometric Characteristic Performance as Recovery rates value

Based on the results of the study on STREK plots [6, 7], the BCP recovery value in the logged-over natural forest after nine years has reached more than 85, which means it is similar to the primary forest condition. The sampling plots in both concessions showed low range values in the range of 11.99 - 23.48 in both scenarios 1 and 2 (Table 5). The implication from BCP value in both concession sampling requires silvicultural action in order to spur productivity and balance the ecology review. In this case, the main thing that caused a low BCP value is the low species composition and lack of stand density. This provides a recommendation that an accelerated recovery is desired by conducting commercial and enrichment planting. A partial approach by [18] indicated after 30 years disturbance having recovery by comparing with an old-growth forest of stem density, average total height and basal area recovered by 57, 48 and 14%, respectively. The need for silvicultural treatment was also identified from forest recovery after human disturbance.

The basic concept in the BCP value of logged-over natural forests is a technique for assessing the proximity of natural forest stands to the conditions of primary forests, that supports the assessment of forest development paradigms to estimate the condition of natural forests that once existed in the area. Variations in the initial conditions and history of forest destruction are very influential on the recovery
assessment. Some environmental factors are the most significant in determining differences in vegetation characteristics and recovery on plots tested [19, 20].

Assessment of forest recovery by vegetation analysis approach to assess the occurrence of succession in secondary forest Dipterocarpaceae aged 8 and 13 years was based on structural dynamics and species composition compared to primary forest conditions. The recovery of forest stands will continue over time [6, 7]. However, the diversity of logged-over forests leads to varying stands, so the length of recovery will vary, depending on the extent of forest degradation and environmental carrying capacity [13, 19]. A similar approach was conducted to assess the recovery of the tropical dry forest after human disturbance in Central Myanmar [18]. Whereas the critical variables were diversity measures and stand structural were compared with the values of an old-growth forest of over 70 years old.

4. Conclusion
Forest stand with vary conditions on age 1-23 years after logging having the BCP value ranged of 11.99-23.48 that indicated a still low recovery rate. This implies that the two research sites still need improvement in the silvicultural technique to accelerate the recovery of stands in the expected direction. The BCP formulation can be used to measure the recovery rates of standing structures on forest after logging towards to the origin or primary forest condition.

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