Tree Species Diversity, Richness and Similarity in Disturbed and Undisturbed Forest of Ketambe Research Station, Southeast Aceh regency

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Abstract. Tree species richness in disturbed and undisturbed site of Ketambe Research Station Ketambe, Southeast Aceh regency, Indonesia has been studied from March to May 2018. Research sites were determined using purposive sampling method. Tree samples were recorded within a plot measuring 400 m² for each sites with a total of 40 plots. Ecological parameters measured in this study were: Density (D), Relative density (RD), Frequency (F), Relative frequency (RF), Dominance (Do), Relative dominance (RD), Importance Value Index (IVI), Shannon’s diversity index (H'), Margalef’s index (RI), and Evenness (E). Estimation of biomass (B) carbon stock (CS) was conducted using allometric equation. Physico-chemical characteristics measured were: air temperature (°C), soil acidity (pH), light intensity (lx), air humidity (%), total organic N (%), and phosphate quantity (ppm) as secondary data. Our study found 79 tree species belonging to 30 families, 61 species in undisturbed site and 47 species in disturbed site. An important species with the highest Importance Value Index (IVI) was Dysoxylum sp.3 in undisturbed site and Macaranga tanarius in disturbed site. The biodiversity was more diverse in undisturbed site (H' = 3.70; RI = 10.93) than disturbed site on the whole study area (H' = 3.47; RI = 9.10). The values of evenness (E) varied between 0.66–0.68 among sites. Estimation of tree biomass and carbon stock followed the similar trend with a total of B = 971.299 Mg/ha and CS = 485.649 Mg/ha on the whole study area. The present study revealed that some vital tree species exist in forest area of Ketambe Research Station as carbon sinks along with their high biodiversities from both disturbed and undisturbed regions. The information on tree species diversity may provide a baseline information for conservation of the biodiversity in this area.

1. Introduction
Forests are habitat for animal and plant communities living in layers and at the surface of the land or in an area, also placed in ecosystems with dynamical balance of nature [1]. Forests in Indonesia are mostly categorized as tropical rainforests in which complex interactions among plant communities occurred. Tropical rainforest is one type of the oldest forest vegetation covering land within 10°N/ 10°S [3].

Ecologically speaking, forests have a vital function in maintaining ecosystem balance. The ecological functions are maintaining micro-climate inside or outside of forest area, producing oxygen and biomasses through carbon sequestration, conserving solar energy and water reservoirs. Regarding the issue of climate change and global warming, one way to protect the ecological function of forests is to treat and maintain forest vegetation from changes in degradation [3]. The current condition of
Indonesia’s forests viewed from an ecological aspect is decreasing due to illegal logging by individuals and companies that have Natural Forest Management Permit/Hak Pengusahaan Hutan (HPH).

Exploitation, deforestation and degradation of tropical forests caused by anthropogenic activities may lead to the extinction of biodiversity [4,5]. The main causes of deforestation and forest degradation are: land clearing for agricultural site, fulfillment of timber needs and development of road infrastructure [6]. Undisturbed forests provide the numerous carbon sinks and sequesters if compared to disturbed forests and other land use systems, because of the high diversity of trees, and the density of vegetation. Changes in the function of the forest will decrease the trees density leading to further decline in carbon assimilation or absorption [7].

Forests have great potential to be included in REDD+ (Reducing Emissions from Deforestation and Degradation). Natural forest conditions that must improve logging have high potential for absorption of carbon from the atmosphere [8]. Carbon is a component of various greenhouse gases, including the most common gas, namely carbon dioxide or CO2. Forest carbon plays an important role in the ecological cycle that contributes to the prevention of global warming by absorbing atmospheric CO2 and storing it [9].

The forest area at the Ketambe research station in Southeast Aceh regency is one type of tropical rain forest that is still considered in good condition. The forest area is also very rich in floral germplasm, inhabited by 17 documented rare plants species such as Rafflesia arnoldi, Magnolia champaca, and Amorphophallus titanum or the largest flower in the world [9]. If the ecological function of the forest is disrupted, then the forest is no longer able to maintain the balance of ecosystems, climate change, global warming, reduced oxygen, increased carbon dioxide, reduced hydrological potential, increased forest vegetation, extinction of endemic flora. Until now, little is known on the tree species diversity and their potentials as carbon sinks of Ketambe research station from both disturbed and undisturbed site. The results of this study then may be used as preliminary data in forest management of this forest.

2. Materials and Method

2.1. Study location and sampling

The study conducted from March to May 2018 located in Ketambe research station, Southeast Aceh regency, Sumatra, Indonesia in two different forest conditions, i.e. disturbed and undisturbed site. Sampling efforts of 40 plots with each plot measuring 400 m² are placed in each site to collect tree species. Sampling point started along 600 m line transect of each site and one plot was placed left to right or in zig-zag pattern within interval of 10 m. Stands or tree species measured in this study must have criterion of diameter at breast height >20 cm above 1.3 m from land surface. Each individual tree was measured and noted for its morphological characteristics while specimens of foliar and generative organs were sampled and preserved in 70% alcoholic solution. Specimens were dried in hot-air oven at 60°C prior authentication to Herbarium Medanese, Universitas Sumatera Utara.

2.2. Data analysis

To analyze specific important tree species in a forest area, an Importance Value Index (IVI) is obtained from calculation of Relative density (RD), Relative frequency (RF) and Relative dominance (RDh) according to [3]:

\[ \text{Density (D)} = \frac{\text{Number of each individual species}}{\text{Size of sampling plot}} \]

\[ \text{Relative Density (RD)} = \frac{\text{Density of a species}}{\text{Total density}} \times 100\% \]
Frequency \((F)\) = \(
\frac{\text{Number of plot inhabited by a species}}{\text{Number of overall plots}}\)

Relative Frequency \((R_F)\) = \(
\frac{\text{Frequency of a species}}{\text{Sum of frequency}}\) \times 100\%

Basal Area \((BA)\) = \(\pi r^2 \text{or} \frac{1}{4} \pi d^2 (\pi = 3.14)\)

Dominance \((Do)\) = \(
\frac{\text{Basal area of a species}}{\text{Total basal area}}\)

Relative Dominance \((R_{Do})\) = \(
\frac{\text{Total dominance of a species}}{\text{Total dominance of all species}}\) \times 100\%

Importance Value Index \((IVI)\) = \(R_D + R_F + R_{Do}\)

The diversity of tree species is calculated using standard diversity index, Shannon’s diversity index \((H')\) as follows:

Shannon's Diversity Index \((H')\) = \(- \sum p_i \ln p_i\)

Where:

\(p_i = \frac{N_i}{N}\)

Note:

\(N_i\) = Sum of individual of a species
\(N\) = Sum of overall species

Meanwhile, a magaleff’s index is also used to assess the species richness according to Odum [11] as follows:

Margaleff’s Index \((R1)\) = \(
\frac{(s - 1)}{\ln(N)}\)

Note:

\(s\) = Number of species
\(N\) = Number of individuals

Equitability index commonly used in ecological analysis is \(E\) by Ludwing and Reynold [12] as follows:

Equitability Index \((E)\) = \(
\frac{H'}{H_{max}}\)

Note:

\(H'\) = Shannon’s Diversity Index
\(H_{max}\) = Index of maximum diversity, depicted as \(\ln S\), where \(S\): Number of genus/ species

Biomass of tree species is calculated using following equation by Brown [13]:

\[ \text{Biomass} \,(B) = Y = \exp\{-2.134 + 2.530 \times \ln(D)\} \]

Note:

\(Y\) = Biomass per tree (kg)
\(D\) = Diameter at breast height (1.3 m)
Estimation of total nitrogen content and phosphate quantity in soil around tree samples within plot are calculated based on Sulaeman [14] by as follow:

\[
\text{Nitrogen content (N)} = \frac{mL \text{ titration (sample} - \text{ blank)} \times \text{ NHCl} \times 14 \times 100}{\text{Weight of soil samples} \times 1000}
\]

\[
\text{Phosphate quantity (P)} = \frac{20}{2} \times \text{dilution factor}
\]

3. Results and Discussion

3.1. Tree species richness

Based on our study, we documented 79 tree species belonging to 30 families. Number of tree species found in undisturbed site is 61 species with density of 241/0.8 ha while in disturbed site is 47 species with density of 156/0.8 ha. Tree species richness in Ketambe research station is presented in Table 1:

| Category | Family           | Species                  | Number of tree |
|----------|------------------|--------------------------|----------------|
| Disturbed| Euphorbiaceae    | Macaranga tanarius       | 16             |
|          | Dilleniaceae     | Dillenia indica          | 13             |
|          | Phyllantaceae    | Phyllatus sp.1           | 12             |
|          | Moraceae         | Aglaia racemosa          | 7              |
|          | Moraceae         | Dalbergia centifolia     | 7              |
|          | Euphorbiaceae    | Mallotus sp.1            | 7              |
|          | Sapindaceae      | Pometia pinnata          | 7              |
|          | Moraceae         | Ficus hispida            | 6              |
|          | Salicaceae       | Salix tetrasperma        | 5              |
|          | Ulmaceae         | Trema orientalis         | 5              |
| Undisturbed| Meliaceae       | Dysoxylum sp. 3          | 18             |
|          | Loasaceae        | Turpinia sphaerocarpa    | 14             |
|          | Meliaceae        | Aglaia racemosa          | 13             |
|          | Euphorbiaceae    | Biscofia javania         | 13             |
|          | Olacaceae        | Strombosia ceylania      | 13             |
|          | Fabaceae         | Carallia brachiata       | 12             |
|          | Sterculiaceae    | Abroma sp.1              | 10             |
|          | Meliaceae        | Azadiradicta excelsa     | 10             |
|          | Moraceae         | Artocarpus elasticus     | 6              |
|          | Euphorbiaceae    | Macaranga tanarius       | 6              |

The highest number of tree species found in undisturbed site is 61 species of 19 families. The results may indicate that environmental condition within the site is still maintained or undisturbed by the local community activities like harvesting timbers or any potential damage to the forest. In addition, physico-chemical factors in undisturbed site are suitable and supportive for the tree growth rather than in disturbed site. The secondary data of current physico-chemical characteristics of study sites is presented in Table 2.

Species dominating the undisturbed site is Dysoxylum sp.3 with 18 individuals. The dominance of this species is assumed due to its evenly distribution of seed propagation, as well as supportive physical and biological factors of undisturbed site to the species growth. The species can be found distributed in primary forest and is thought to be intolerant to sunlight, with morphological features in the form of large stem diameters, rare branches and hardwood textures. Indriyanto [15] states that
Dysoxylum is a plant species commonly found in humid environment or primary forest with A or B climate type.

In disturbed site, 47 species of trees were found belonging to 24 families. The low number of species in disturbed forests is assumed due to unfavorable environmental conditions because forest ecosystems are disrupted by illegal logging. The dominant species in the forest is Macaranga tanarius (Euphorbiaceae) with a 16 number of individuals. The dominance of Macaranga tanarius in the disturbed site, was presumably due to the small size of the seeds which facilitates dispersion, rapid seed germination, and tolerance to sunlight. This is in accordance with the statement of Polunim [16], the dispersion of small-sized seeds with the help of carriers, i.e. water, animals and wind can reach distances of hundreds of miles and will grow into new individuals after obtaining the appropriate conditions. Furthermore, Sahar [17] states that the damage that occurs in climax forests will cause the opening of tree canopies allowing sunlight to penetrate the forest floor, thereby stimulating germination and seed growth. The species is distributed in secondary forests, tolerant to sunlight and is a pioneer plant, hence the seeds are easily spread by squirrels or birds. Huc [18] states that pioneer trees have the easiest dispersal mechanisms that allow certain species to having an extensive geographic distribution.

3.2. Basal area of vegetation

Comparison of the percentage of basal area (BA) between disturbed and undisturbed sites from 8 families with the largest number is presented in Figure 1.

![Figure 1. Basal area percentage of 8 families between undisturbed and disturbed site at Ketambe research station](image)

The plant family, Meliaceae has the highest BA with a value of 43%, and the lowest is Burseraceae of 1% in the undisturbed site. The high value of BA for Meliaceae indicated the absence of forest disturbance allowing the species to be found in many locations. Meanwhile, Euphorbiaceae has the highest BA with a value of 36% and the lowest is also found in Burseraceae family of 1%. The highest BA percentage of both Meliaceae and Euphorbiaceae at the Ketambe research station is thought to be an ideal and relevant environment for growth, as well as the large number of tree species which can be found in each family. Suhedang [19], states that the stand structure describes the distribution of stand dimensions (basal area per hectare or number of trees per hectare) at various tree diameter sizes. Furthermore, Kacholi [20] states density, basal area, and frequency of distribution can further describe the structure of the forest.

3.3. Importance Value Index (IVI)

Analysis of tree species richness revealed a different results between undisturbed and disturbed site at Ketambe research station. The overall results can be seen in Table 2 and Table 3.
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Table 2. Important value index (IVI), relative density (R_D), relative frequency (R_F) and relative dominance (R_Dn) of 10 dominant tree species at undisturbed site

| N  | Species                      | R_D (%) | R_F (%) | R_Dn (%) | IVI (%) |
|----|------------------------------|---------|---------|----------|---------|
| 1  | *Dysoxylum* sp. 3            | 7.47    | 5.33    | 16.68    | 29.47   |
| 2  | *Bischofia javanica*         | 5.39    | 5.33    | 8.70     | 19.42   |
| 3  | *Turpinia sphaeroacarpa*     | 5.81    | 3.55    | 10.09    | 19.45   |
| 4  | *Strombosis ceylania*        | 5.39    | 2.96    | 8.70     | 17.05   |
| 5  | *Pometia pinnata*            | 5.39    | 4.14    | 8.70     | 18.23   |
| 6  | *Aglaia racemosa*            | 5.39    | 4.73    | 8.70     | 18.83   |
| 7  | *Carallia brachiata*         | 4.98    | 3.55    | 7.41     | 15.94   |
| 8  | *Azadiradicta excelsa*       | 4.15    | 3.55    | 5.15     | 12.85   |
| 9  | *Abroma sp.1*                | 4.15    | 2.96    | 5.15     | 12.25   |
| 10 | *Artocarpus elasticus*       | 2.49    | 2.37    | 1.85     | 6.71    |
|    | **Total**                    | 100.00  | 100.00  | 100.00   | 300.00  |

Table 3. Important value index (IVI), relative density (R_D), relative frequency (R_F) and relative dominance (R_Dn) of 10 dominant tree species at disturbed site

| N  | Species                      | R_D (%) | R_F (%) | R_Dn (%) | IVI (%) |
|----|------------------------------|---------|---------|----------|---------|
| 1  | *Macaranga tanarius*         | 10.26   | 10.62   | 24.76    | 45.63   |
| 2  | *Parashorea lucida*          | 8.33    | 6.19    | 16.34    | 30.87   |
| 3  | *Phyllantus sp.1*            | 7.69    | 3.54    | 13.93    | 25.16   |
| 4  | *Dalbergia centifolia*       | 4.49    | 4.42    | 4.74     | 13.65   |
| 5  | *Pometia pinnata*            | 4.49    | 5.31    | 4.74     | 14.54   |
| 6  | *Aglaia racemosa*            | 4.49    | 5.31    | 4.74     | 14.54   |
| 7  | *Mallotus sp.1*              | 4.49    | 4.42    | 4.74     | 13.65   |
| 8  | *Ficus sp.1*                 | 3.85    | 1.77    | 3.48     | 9.10    |
| 9  | *Salix tetrasperma*          | 3.21    | 2.65    | 2.42     | 8.28    |
| 10 | *Trema orientalis*           | 3.21    | 1.77    | 2.42     | 7.39    |
|    | **Total**                    | 100.00  | 100.00  | 100.00   | 300.00  |

From the table, it can be seen that the R_D value of trees in undisturbed forests ranges between 0.41–7.47%, the R_F value ranges between 0.59–5.33%, the R_Dn value ranges between 0.05–16.68%, and the IVI value is 1.06–29.47%. The highest R_D, R_F, R_Dn, and IVI values were obtained from *Dysoxylum* sp.3, while the lowest was obtained in other 19 tree species including *Ficus* sp.1, and *Lithocarpus* sp.1. The high R_D value of this species indicates a success of seed germination, and the number of species was mostly found at an altitude of 450–1000 m a.s.l. The speed of seed germination characterized by the large number of individuals is one of the factors that determine the ability of a plant species to deal with and overcome intra- or interspecific competition [3]. The dominant species, *Dysoxylum* sp.3 indicated a specific ecological role in a plant community within the forest area. The dominance of this type is indicated by the highest IVI ranging from 1.06–29.47%. The high value of IVI indicates that the species is able to adapt to the surrounding environment better than other species [21].

The highest R_D value in disturbed forest was shown by *Macaranga tanarius* with values ranging from 0.64–10.26%, while the lowest was found in other 18 species including *Artocarpus* sp.1, and *Neesia* sp. The R_F value ranges between 0.88–10.62% with the highest shown by *M. tanarius* while the lowest was found in other 22 species including *Baccaurea deflexa*, and *Artocarpus nitidus*. The high R_F value of *M. tanarius* was due to our finding of this species in almost all plots. Suin [22] stated that relative frequencies can describe the criteria for the spread of plant species in an area.

The R_Dn values in disturbed forests range from 0.10–24.76% with the highest value obtained from *M. tanarius* while the lowest from *Eleocarpus* sp.1. The high R_Dn value *M. tanarius* shows that there are many species of this tree found in disturbed forests. In addition, from observations in the field *M.*
*tanarius* produced a large number of individuals and intolerant to sunlight so as to facilitate seed germination. According to Indriyanto [3], the magnitude $R_{Dv}$ value is determined by the size of the tree diameter and the number of individuals of a species in location.

The IVI value in disturbed forests range from 1.62–45.63%, the highest value was again obtained from *M. tanarius* while the lowest was obtained in other 19 species including *Mangifera kemanga*. Generally important species is a species with large productivity [22]. The higher the IVI value of a species, the greater the level of its domination in a particular community or vice versa [23]. The domination of certain species in a community if the species succeeds in placing most of the available resources compared to other species [24].

3.4. Ecological analysis of tree species diversity

In general, the overall ecological parameters in this study showed that the most diverse tree species was obtained in undisturbed site rather than in disturbed site. The Shannon’s diversity index ($H'$) range between 3.47–3.70. The higher the value of $H'$, the more diverse of plant community in forest ecosystem. The $H'$ is always directly proportional to $E$ value.

![Figure 2](image.png)

*Figure 2.* Shannon’s diversity index ($H'$), Margaleff’s index ($R_1$), and Equitability index ($E$) of tree species diversity from disturbed and undisturbed site at Ketambe research station

The higher the diversity value of an area indicates the more stable the community in the region [25]. Comparison of species diversity in each forest community shows that the diversity of tree species in undisturbed forests is higher compared to disturbed forests. The presence of several species of trees in disturbed forests is the species that have the ability to live and adapt to the environmental changes in the forest.

Based on Magurran [26] the amount of $R_1 < 3.5$ shows that species richness is low, $R_1$ between 3.5 and 5.0 shows that species richness is moderate and $R_1 > 5.0$ indicates a high diversity. The Margalef’s ($R_1$) index value in undisturbed forest is 10.92 higher when compared to disturbed forest with a value of 9.10. Based on the criterion, both forest conditions inhabited by a high species richness. The Equitability value ($E$) < 0.3 indicates low species evenness, $E$ between 0.3 to 0.6 indicates moderate evenness is classified as uniform. Hence, in our study, the $E$ value range between 0.66–0.68 indicating a uniformity of certain physico-chemical that support the plant community.

Potential carbon stocks and biomass of tree species within two study sites is presented in Table 4. The results show that carbon biomass and stored carbon have a higher value in the undisturbed site
when compared to the undisturbed site. This is influenced by the decreasing number of individuals or the smaller diameter of the tree. Tree biomass is influenced by climate factors such as rainfall, stand age, historical development of vegetation, composition and stand structure [27]. Furthermore, Hairiah [7] explained that a land use system consisting of trees with species that have high wood density values, bombasses would be higher when compared to land that has species with low wood density values. The mean measurements of physico-chemical characteristics of both study sites are presented in Table 5.

**Table 4. Potential biomass and carbon stocks of tree species at Ketambe research station**

| Category  | Biomass (Mg.ha\(^{-1}\)) | Carbon stock (Mg.ha\(^{-1}\)) |
|-----------|--------------------------|-------------------------------|
| Undisturbed | 557.662 | 278.831 |
| Disturbed  | 413.637 | 206.818 |
| Total      | 971.299 | 485.649 |

**Table 5. Mean physico-chemical measurements of study sites at Ketambe research station**

| Category | Physico-chemical parameters | Air temperature \(^{\circ}\)C | Soil pH | Light intensity (lx) | Air humidity (%) | Total –N (%) | Phosphate quantity (ppm) |
|-----------|-----------------------------|-----------------------------|--------|----------------------|-----------------|--------------|--------------------------|
| Undisturbed |                             | 25                          | 6.5    | 600                  | 92              | 0.95         | 10.00                    |
| Disturbed  |                             | 27                          | 5.8    | 1560                 | 87              | 0.37         | 7.74                     |

The parameter, light intensity is different between the two sites, along with parameters, i.e. air temperature and humidity with fluctuating result. The light intensity in disturbed site increases higher proportional with an increase in temperature. The more intense light intensity is caused due to the presence of falling trees forming a gap in forest. The gaps are supported by illegal logging and anthropogenic activities. Poerwowidodo [28] stated that the development of plant roots can be constrained by physical or chemical barriers. Physical barriers are mainly caused by solid soil conditions, as a result of high clay content or compaction.

Our study also found that the –N content and phosphorus content are higher in undisturbed compared to the disturbed site. The percentage of N content in present study is 0.37–0.95%, higher than previously reported by Ihsan [29] obtaining a total N value of 0.42–0.57%. The low N value obtained in disturbed forests is thought to be due to the disruption of the nitrogen cycle which is generally played by bacteria through the processes of fixation, assimilation, ammonification, reduction, nitrification and denitrification. The difference in the value of N between two study sites was due to nutrient washing processes directly caused by lack of canopy cover and the inability of plants in absorbing soil nutrients. Organic matter has a very important role in the soil, especially its effect on soil fertility [30]. The ability of a tree to absorb nutrients both passively and actively is an important factor that determines tree growth well so that it can increase overall forest growth [31].

Phosphorus (P) and potassium (K) are macronutrients other than nitrogen (N) needed by plants for their growth and development. Phosphorus also plays an important role in photosynthesis. Potassium also functions as a catalyst, regulates physiological and metabolic processes in cells and increases nutrient absorption [32]. P element is needed for the formation of flower primodia and plant organs for reproduction, accelerating the maturation of fruits and seeds [33]. Furthermore, element P has an important role for carbon sequestration in tropical forests, the low phosphorus content in the soil will cause a reduced ability of forests to absorb carbon. Based on the conditions of some of the soil chemical properties parameters mentioned above, it can be concluded that the soil fertility status in the study area is classified in high content of nutrients [34].
4. Conclusion
Tree species richness, diversity and ecological importance has been studied in disturbed and undisturbed forest of Ketambe research station, Southeast Aceh, Indonesia. Our study found 79 tree species belonging to 30 families, 61 species in undisturbed site and 47 species in disturbed site. An important species with the highest Importance Value Index (IVI) was *Dysoxylum* sp.3 in undisturbed site and *Macaranga tanarius* in disturbed site. The biodiversity was more diverse in undisturbed site ($H' = 3.70; RI = 10.93$) than disturbed site on the whole study area ($H' = 3.47; RI = 9.10$). The values of evenness ($E$) varied between 0.66–0.68 among sites. Estimation of tree biomass and carbon stock followed the similar trend with a total of B = 971.299 Mg/ha and CS = 485.649 Mg/ha on the whole study area. The present study revealed that some vital tree species exist in forest area of Ketambe Research Station as carbon sinks along with their high biodiversities from both disturbed and undisturbed regions. The information on tree species diversity may provide a baseline information for conservation of the biodiversity in this area.

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