Tree species diversity on ebony habitat with different degradation levels in Sulawesi

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Abstract. Ebony (Diospyros celebica Bakh.) is endemic species to Sulawesi that is experiencing population decline. It is known that population size is an important element for the dynamics of natural forests through changes in vegetation structure and composition that need to be monitored. This study aims to analyze the species diversity in natural habitats of genetically diverse ebony, namely: i) Bantimurung National Park (BB), ii) Cani Sirenreng Nature Park (CS), iii) Farhumpenai Nature Reserve (FP), and iv) Pangi Binangga Nature Reserve (PB). Data collection was carried out based on a modified transect line and plot with 20 m x 100 m in size. The results showed that as many as 28 families were identified, consisting of 44 species at the tree level, 37 species at the pole level, 39 species at the sapling level, and 31 species at the seedling level, respectively. The composition of vegetation in Babul National Park consists of 32 species, Cani Sirenreng consists of 18 species, Farhumpenai consists of 19 species, and Pangi Binanngga consists of 19 species. The species composition was dominated by Diospyros celebica Bakh., Dracontomelon dao (Blanco) Merr. & Rolfe, Canangium odoratum, Ficus benjamina L., Pterospermum celebicum Miq., Kleinhovia hospita L. and Vitex cofassus Reinw. Ex Blume. The diversity index (H’-Index) of tree species in BB, CS, FP, and PB were 0.82, 1.13, 1.03, and 1.60, respectively. The Important Value Index (INP-Index) of ebony in BB, CS, FP, and PB were 18.01%, 74.1%, 60.13% and 113.5%, respectively. The structure of the forest canopy layer in BB and FP consists of three layers of canopy, while CS and PB consist of two layers of canopy.

1. Introduction

Ebony (Diospyros celebica Bakh.) is one of the endemic species that can only be found naturally on the island of Sulawesi. The distribution is almost on all areas in Sulawesi, such as South Sulawesi, West Sulawesi, Central Sulawesi, and North Sulawesi [1]. Ebony wood is strong, luxurious, and beautiful based on its characteristics, which is now increasingly becoming rare [2]. The use of ebony for various purposes from year to year is increasing, so that concerns about the decline in the ebony population are increasingly evident [3]. The distribution and abundance of ebony in Sulawesi's natural forests decrease...
due to the past massive exploitation. Therefore, in 2000, The International Union for the Conservation of Nature (IUCN) Red List of Threatened Species categorized *Diospyros celebica* Bakh. in a vulnerable status (vulnerable A1 cd), which means it is at high risk for extinction and very vulnerable to the exploitation [4].

The current distribution and potential of ebony in Sulawesi are not well updated, considering that the occurrence of illegal logging activities and land conversion for definite settlement that impacts the condition of natural stands in Sulawesi's natural forests is very obvious. The decrease in the quantity and quality of trees as a key component in natural forests, including ebony, can influence the structure of forest vegetation to form resilient stands that reflect the dynamics of natural regeneration. Commonly, remaining natural stands can be found in protected forests located in hilly areas with poor nutrient conditions [5]. Therefore, it is necessary to monitor the existing habitat condition for in situ ebony conservation, focusing on the vegetation structure and the abundance of ebony species, including other tree species composition. However, updates on the data on the existing habitat of Ebony are not always available. Therefore this study was conducted with the objective of analyzing species diversity in selected natural ebony habitats based on the different forest degradation levels.

2. Material and methods

2.1. Data collection

This study was conducted from October 2020 to January 2021 in natural ebony habitats in Sulawesi's natural forests by referring to the previous unpublished information on the high level of genetic diversity of ebony. Several locations classified as harboring high genetic diversity were used as research locations, namely: Pangi Binanngga Nature Reserve (0.348), Cani Sirenreng Nature Park (0.325), Bantimurung Bulusaraung National Park (0.292), and Farhumpenai Nature Reserve (0.252) [6].

The tools and types of equipment used in the field included tape meter, phi band, plastic rope, compass, stake, Haga hypsometer, hygrometer, clinometer, lux meter, machete, species identification book, cutter, GPS, and digital camera. The materials used were tally sheets, a permanent marker, stationery, and labels.

2.2. Research procedure

The study was conducted with the following activities:

2.2.1. Vegetation structure and composition. The data was collected using a combination of the line transect and plots method [7]. The sample size of the strip plot was determined to be 20 m x 100 m with a model of 100 m as the X-axis and 20 m as the Y-axis. The strip plot is divided into five subplots, 20 m x 20 m.

2.2.2. Vegetation analysis. The data parameters for the growth rate of poles and trees were species name, number of individuals, diameter at breast height (DBH), and total height [8].

2.2.3. Forest stand profile design and crown stratification. The data collected was included: species identity, total height, branch-free height, diameter, tree position, and tree distance to the path axis, as well as a crown sketch.

2.2.4. Characteristics of the growing sites. Environmental data parameters were collected, namely: temperature, slope, altitude, and light intensity. The temperature was measured by a hygrometer, altitude measurement using GPS, and light intensity using a lux meter. Data collection of environmental conditions was carried out in the vegetation analysis plot.
2.3. Data analysis

Vegetation analyses were carried out by calculating several indices using some of the formulas that were used in the previous studies. Processing of data from analysis of vegetation includes:

a. Important Value Index (INP-Index) is a quantitative parameter used to determine the level of dominance of species in a plant community. INP calculation is determined by analyzing quantitative parameters of vegetation [9].

b. The Species Diversity Index (H') was calculated using the Shanon-Winner Index of General Diversity formula. If the value of H'<1, then it is included in the low category, the value of 1<H'<3 is included in the medium category and will be included in the high category if H'>3 [10].

c. Species Evenness Index (E) shows the level of individual evenness per species. If the value of E is close to 1, then the evenness value is high [11].

d. Species Richness Index (R) was determined using the Margallef formulation. If the value of R < 3.5, then the species richness is low, the value of 3.5 < R < 5.0 indicates that the species richness is classified as moderate, and if it shows R> 5.0, then the species richness is classified as high [11].

e. Species Dominance Index (C) was used to determine the dominance of a species in a community. Species Dominance Index values range from 0 ≤ C ≤ 1. This index was calculated using the formula used in the previous studies [12].

3. Results and discussion

3.1. General condition in research sites

The selected research locations to study the forest vegetation structure on Sulawesi Island are spread over 4 locations, i.e., Bantimurung Bulusaraung National Park, Cani Sirenreng Nature Park, Farhumpenai Nature Park Reserve, and Pangi Binangga Nature Reserve. The general condition and environmental conditions in all research locations have different characteristics (table 1). Variables of soil type, altitude, climate, and rainfall become apparent differences. It has an impact on the presence of vegetation in a community [13]. Environmental conditions can also cause genetic differences of species in different ecosystems. The results of chemical testing on ebony show that the extractive content of ebony in the West Sulawesi location has a very significant difference with ebony in South Sulawesi [14].

| Description       | BB                  | CS                  | FP                  | PB                  |
|-------------------|---------------------|---------------------|---------------------|---------------------|
| Type of soil      | Rendolls dan Eutropets | Lithosol            | Alluvial, Latosol and Podzolic | Hapluterts and Haplutepts |
| Topography        | Flat, hilly, and mountainous | Hilly and valley   | Flat, hilly, and mountainous | Hilly and mountainous |
| Slope             | 0-45%               | 0-45%               | 30-80%              | 20-80%              |
| Climate           | Type D (Schmidt and Ferguson) | Type C (Schmidt and Ferguson) | Type A dan B1 (Schmidt and Ferguson) | Type A (Schmidt and Ferguson) |
| Rainfall          | 2,500 mm/year       | 3,000 mm/year       | 4,364 mm/year       | 2,355 mm/year       |
| Altitude          | 287 masl            | 493 masl            | 381 masl            | 100 masl            |
| Temperature       | 28 °C               | 24 °C               | 26 °C               | 28 °C               |
| Relative humidity | 75%                 | 89%                 | 89%                 | 80%                 |

Note: BB (Babul National Park), CS (Cani Sirenreng), FP (Farhumpenai) and PB (Pangi Binangga)
3.2. Species composition

The study showed the results on the structure of vegetation in four locations spread across Sulawesi Island, which found as many as 67 species. The identification results also showed that there were 30 families dominated by the Moraceae, Malvaceae, Meliaceae, Anacardiaceae, and Fabaceae. The vegetation composition in Babul National Park consists of 19 families with 32 species. Cani Sirenreng consists of 14 families with 18 species. Farhumpenai consists of 15 families with 19 species, and Pangi Binangga consists of 11 families with 19 species (figure 1). Especially in the Moraceae family can usually be found in various vegetation types, especially in primary forests in Sulawesi [15].

![Vegetation composition in the four research sites](image)

Figure 1. Vegetation composition in the four research sites

The distribution of forest plants at each location is classified into three groups based on the presence of each species. The first group is plant species found in all sites, i.e., Macassar ebony (*Diospyros celebica* Bakh.). Macassar ebony is one of the endemic species to Sulawesi Island. Its natural habitats are spread over several regions in South Sulawesi, West Sulawesi, and Central Sulawesi [16].

The second group consists of several species that are frequently found in several sites. The plant species is *Dracontomelon dao* (Blanco) Merr. & Rolfe., *Canangium odoratum* (Lam.) Baill. ex King, *Pterospermum celebicum* Miq., *Ficus benjamina* L., *Kleinhovia hospita* L. and *Vitex cofassus* Reinw. Ex Blume. These are the local species widely distributed on the Sulawesi Island and used by the community due to their economic value [17, 18, 19, 20].

The third group is forest plant species that were only found at one study site. In Babul National Park, there are 16 species; Cani Sirenreng, there are eight species; Farhumpenai, which has eight species and Pangi Binangga has 14 species. Differences in the composition of vegetation in each forest area are closely related to habitat conditions. One of the environmental factors that can affect the existence and richness of species is altitude. Differences in height where it grows will be a limiting factor for plant growth due to differences in soil conditions, temperature, light intensity, and water availability [13].

3.3. Important value index (INP-Index)

At the research location, there are differences in the Important Value Index (INP-Index) at each level of growth. The INP-Index is obtained from the sum of the relative values based on three parameters (relative density, relative frequency, and relative dominance), resulting in very varied values for each vegetation species to provide an overview of the role of species in their community [8].

Table 2 shows that the dominant pole-level species in the BB location is *Knema cinerea* (Poir.) Warb. (85.871%), CS location is *Diospyros celebica* Bakh. (45.749%), FP location is *Diospyros celebica* Bakh. (29.885%) and the location of the PB was *Theobroma cacao* L. (203.437%). PB site is an agroforestry area used by the community to grow plantation crops, namely cocoa (*Theobroma cacao*)
The agroforestry system can increase land productivity by planting mixed crops in annual and seasonal crops. Planting commercial species will affect the density of a species due to the tendency of the community to plant species that have economic value [21]. The results also show that Macassar ebony regeneration at the pole level was founded at the CS and FP sites. Therefore, natural Macassar ebony regeneration is still potential and not disturbed. The ability of native species to achieve higher growth rates proves that these species can adapt to ecosystems or forest vegetation types [8].

**Table 2.** Top Three Highest INP-Index pole-level in various research locations

| No. | Species                               | Family      | KR (%) | FR (%) | DR (%) | INP (%) |
|-----|---------------------------------------|-------------|--------|--------|--------|---------|
| I. BB | **Knema cinerea** (Poir.) Warb.       | Moraceae    | 29.411 | 28.571 | 27.888 | 85.871  |
|      | **Cryptocarya ferrea** Blume          | Lauraceae   | 11.764 | 7.142  | 8.36   | 27.274  |
|      | **Palaquium obavatum** (Griff.) Engl. | Sapotaceae  | 11.764 | 7.142  | 7.968  | 26.875  |
| II. CS | **Diospyros celebica** Bakh.          | Ebenaceae   | 17.241 | 14.285 | 14.222 | 45.749  |
|      | **Arthrophyllum diversifolium** Blume | Araliaceae  | 13.793 | 14.285 | 14.479 | 42.558  |
|      | **Ficus spp.**                        | Moraceae    | 10.334 | 10.714 | 12.463 | 33.522  |
| III. FP | **Diospyros celebica** Bakh.      | Ebenaceae   | 10.344 | 13.636 | 5.904  | 29.885  |
|      | **Palaquium obavatum** (Griff.) Engl. | Sapotaceae  | 10.344 | 9.09   | 10.418 | 29.854  |
|      | **Elmerrillia tsiampacca** (L.) Dandy | Magnoliaceae | 10.334 | 9.09   | 9.6    | 29.036  |
| IV. PB | **Theobroma cacao** L.                | Malvaceae   | 74.285 | 33.333 | 95.818 | 203.437 |
|      | **Dracontomelon dao** (Blanco) Merr. & Rolfe. | Anacardiaceae | 2.875 | 8.333  | 0.612  | 11.803  |
|      | **Chisocheton macrophyllus** King.    | Meliaceae   | 2.875  | 8.333  | 0.612  | 11.803  |

Note: BB (Babul National Park), CS (Cani Sirenreng), FP (Farhumpenai) and PB (Pangi Binangga)

**Table 3.** Tree-level INP-Index at various research sites

| No. | Species                               | Family      | KR (%) | FR (%) | DR (%) | INP (%) |
|-----|---------------------------------------|-------------|--------|--------|--------|---------|
| I. BB | **Canangium odoratum** (Lam.) Baill. ex King | Moraceae    | 10     | 9.375  | 13.349 | 32.724  |
|      | **Knema cinerea** (Poir.) Warb.       | Myristicaceae | 12.5   | 9.375  | 8.864  | 30.379  |
|      | **Cryptocarya ferrea** Blume          | Lauraceae   | 7.5    | 6.25   | 14.079 | 27.829  |
| II. CS | **Diospyros celebica** Bakh.          | Ebenaceae   | 25.806 | 20.833 | 27.466 | 60.133  |
|      | **Canangium odoratum** (Lam.) Baill. ex King | Annonaceae  | 12.903 | 12.5   | 13.22  | 38.623  |
|      | **Polyscias nodosa** (Blume) Seem.    | Araliaceae  | 9.677  | 12.5   | 8.089  | 30.267  |
| III. FP | **Diospyros celebica** Bakh.      | Ebenaceae   | 21.621 | 16     | 25.511 | 60.133  |
|      | **Ficus benjamina** L.                | Moraceae    | 5.405  | 8      | 14.907 | 28.313  |
|      | **Nauclea orientalis** (Blume) Merr. | Rubiaceae   | 10.81  | 12     | 5.316  | 28.127  |
| IV. PB | **Diospyros celebica** Bakh.          | Ebenaceae   | 41.176 | 22.222 | 50.12  | 113.519 |
|      | **Kleinhovia hospita** L.             | Sterculiaceae | 14.705 | 16.666 | 10.45  | 41.822  |
|      | **Chisocheton macrophyllus** King.    | Meliaceae   | 11.764 | 11.111 | 5.385  | 28.261  |

Note: BB (Babul National Park), CS (Cani Sirenreng), FP (Farhumpenai) and PB (Pangi Binangga)

Based on table 3, the species at the tree level that dominates at the BB location is **Canangium odoratum** (32.73%), the CS location is **Diospyros celebica** Bakh. (74.1%), while at FP location is **Diospyros celebica** Bakh. (74.1%).
Diospyros celebica Bakh. (29.9%) and the location of the PB is Diospyros celebica Bakh. (113.5%). At the tree level, Diospyros celebica Bakh. is dominant in three locations, namely CS, FP, and PB. Forest areas located in CS, FP, and PB can be used as genetic resources for the Diospyros celebica Bakh. species because it has potential genetic resources that can produce large numbers of seedlings or saplings [4, 15, 16]. Based on the study results, the presence of ebony at each research location showed a different response. The data shows that the CS, FP, and PB sites have complete Diospyros celebica Bakh. at all growth levels, which means natural regeneration at the study site is good.

3.4. Species diversity index (H'), species svenness index (E), species richness index (R), and species dominance index (C)

Table 4 shows that the Diversity Index (H') value in all research locations at various growth levels is almost constant. In general, the value of H' in all sites at multiple levels is low (H'<1) and moderate (1<H'<3.5). The diversity index at the highest pole level was at CS location (1.126), and the highest tree level was at BB location (1.232). In general, H' for all growth levels and all research plots is low, meaning that the number of species is small and the variation in the number of individuals of each species is also small. It means that some of the research plots may have been disturbed.

### Table 4. Vegetation Indices in each research location

| Growth level | Vegetation Indices | BB       | CS       | FP       | PB       |
|--------------|-------------------|----------|----------|----------|----------|
| Poles        | H'    | E     | R     | C     |
| BB           | 0.954 | 0.397 | 3.529 | 0.141 |
| CS           | 1.232 | 0.411 | 5.15  | 0.067 |
| Trees        | 1.126 | 0.406 | 4.454 | 0.089 |
| Fp           | 0.971 | 0.391 | 3.203 | 0.132 |
| Poles        | 0.916 | 0.347 | 3.86  | 0.082 |
| PB           | 1.033 | 0.416 | 3.046 | 0.109 |
| Trees        | 0.850 | 0.342 | 3.119 | 0.217 |

Note: BB (Babul National Park), CS (Cani Sirenteng), FP (Farhumpenai) and PB (Pangi Binangga)

Overall, at the study site, the various growth level of the species was not evenly distributed (Table 7). At the pole level, the evenness index (E) is low except at the CS location (0.406), and the tree-level at the CS location (0.391) and PB (0.342) has a lower Evenness Index than the BB location (0.411) and FP (0.416). The low value of E reflects that in the research sites, there is species dominance. It indicates that the presence of certain species is very dominant over other species.

Table 7 also shows that most research sites at the growth level of poles and trees have high Species Richness Index values, except for PB locations (R<3.5). The highest Species Richness Index value in all sites was at BB location at the tree level with a value of 5.15 (R>3.5). The difference in the wealth index in each community is due to differences in habitat conditions and different areas. The value of the species dominance index, which is getting closer to 1, indicates dominated by a species in the community. Table 7 presents data showing that all study sites at various growth levels (except pole level PB) had shallow Species Dominance Index values (C<1). While at the PB location, the sapling level has a species dominance value of 0.560, which is classified as moderate. It is caused by the location of PB in an agroforestry area dominated by the species Theobroma cacao L. planted by the local community.

Diversity values result from a community with a high level of species richness but low evenness or low species richness but high evenness [22]. The vegetation composition with species with a low number
of individuals will affect the regeneration process in natural forests. The availability of regeneration in multi-levels is one of the prerequisites for the sustainability of natural regeneration in the ecosystem [8]. The value of the species richness index is highly dependent on the number of species found and the dominance of certain species in an observation plot in the community [22]. Usually, the species dominance index in the natural forest has a shallow value (C<0.5), which means the dominance that occurs in the natural forest is relatively balanced and spreads over each species [23].

3.5. Stand profile and canopy stratification

Figure 2 shows that the BB, FP, and CS locations have a high accumulation of density values compared to PB. The resulting density value is in line with the measurement results of light intensity at the research location. BB, CS, FP, and PB sites have values of 902 lux, 876 lux, 763 lux, and 1192 lux, respectively. The canopy cover in areas with a very high density impacts the low intensity of light penetrating the forest floor.

Vertical stand structure was formed based on tree density and tree height class (canopy layer) data. Figure 3 shows that the forest vegetation was composed of 3 layers of the canopy in all study locations, namely stratum A, stratum B, and stratum C. At location BB, stratum A consisted of Diospyros celebica Bakh., Dracontomelon dao (Blanco) Merr. & Rolfe., and Cryptocarya ferrea Blume. Stratum B is dominated by Knema cinerea (Poir.) Warb., Palaquium obavatum (Griff.) Engl. and Cryptocarya ferrea Blume. Stratum C is dominated by Knema cinerea (Poir.) Warb. and Beilschmiedia genniflora (Blume) Kosterm. The CS location in Stratum A, B, and C Diospyros celebica Bakh defeated it. Several other species found in each stratum are Gmelina arborea Robx. ex Sm, Canangium odoratum (Lam.) Baill. ex King, Dillenia serrata Thunb and Garcinia siyqifolia Pierre. At the location of the FP type Palaquium obavatum (Griff.) Engl., Dracontomelon dao (Blanco) Merr. & Rolf. and Diospyros celebica Bakh. found in all header layers. Several species were found in each stratum: Nauclea orientalis (Blume) Merr., Pterospermum celebicum Miq., Elmerrillia tsiampacca (L.) Dandy, and Alstonia scholaris (L.) R.Br. Besides it, in the PB location, the dominant species in stratum A and B was Diospyros celebica Bakh. and in stratum C dominated by Theobroma cacao L.

![Figure 2. Estimated densities at the different growth levels in various research locations](image-url)
Figure 3. The number of species at various stages of growth at each study site

Figure 4. Stand profile and canopy stratification (A) BB, (B) CS, (C) FP, and (D) PB

The vertical stand structure in tropical rain forests usually forms three canopy layers, namely stratum A, stratum B, and stratum C. Differences in tree height in a community will create a canopy layer (stratification) [9]. The formation of the canopy is due to two crucial things experienced by vegetation in the community due to interactions between species, namely competition and light tolerance [7]. A typical phenomenon occurs when the density of stratum A is smaller than the stratum below it. If stratum A has a higher species than the other stratum, then species loss occurs due to the inability to adapt. The availability and presence of stands in typical forests will form an inverted J curve. It will guarantee the sustainability of the stands in the future [24]. The forest vegetation structure that formed an inverted J curve will result in a secondary succession process in line with the increase in time [25].
4. Conclusion
The results concluded that there were found in all research locations as many as 30 families consisted of 44 species in the tree class, 37 species in the pole class, 39 species in the sapling class, and 31 species in the seedling class. The species composition in all study sites was dominated by *Diospyros celebica* Bakh., *Draccontemelon dao* (Blanco) Merr. & Rolfe, *Canangium odoratum*, *Ficus benjamina* L., *Pterospermum celebicum* Miq., *Kleinhovia hospita* L. and *Vitex cofassus* Reinw. ex Blume. BB, CS, FP, and PB have a tree diversity index of 0.82, 1.13, 1.03, and 1.60. The important value index (INP-Index) of ebony on tree growth levels in BB is 18.01%, CS is 74.1%, FP is 60.13%, and PB is 113.5%. The structure of the forest canopy layer in BB, CS, FP, and PB consists of three canopy layers with different density conditions. At the CS and FP locations, *Diospyros celebica* Bakh was complete at all growth levels so that the natural regeneration at the research site took place well.

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