The diversity of plant species in the proboscis monkey's habitat as a species reference for habitat restoration

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Abstract. Most of the Proboscis monkey (Nasalis larvatus) habitat is outside the protected area, so the potential for destruction is high. One of the efforts to improve its habitat is habitat restoration. This study aims to determine plant species for proboscis monkey habitat restoration based on reference habitats. The research was conducted at eight locations in East Kalimantan, Indonesia i.e. Kuala Samboja, Mahakam Delta, Suwi River, Ohong River, Berau Delta (mangrove and riverine), Sungai Wain, and Kutai National Park. Vegetation analysis with line-plot sampling method with a total sample of all locations of 11.7 ha. The results showed that the habitat included three main types: mangrove, riverine, and riverine-near coastal. A total of 152 tree species, 41 of which were potential proboscis monkey feed. The highest plant species diversity value was in the riverine forest-Berau Delta of 1.25, while the lowest was in the mangrove forest-Berau Delta of 0.54. Species that are a food source and have good adaptation in riverine habitat are Vitex pinnata, Dillenia excelsa, Garcinia spp, Heritiera littoralis, Ilex cymosa, Cerbera manghas, Hevea brasiliensis, and Sonneratia caseolaris. Whereas in mangrove habitat are Avicennia alba, A. officinalis, Bruguiera gymnorrhiza, B. parvifolia, Rhizophora apiculata, and S. alba. They are recommended for habitat restoration.

1. Introduction

Kalimantan has broad tropical forests and is a habitat for diverse plants and animals. However, various economic interests cause damage and loss of animal habitats. The proboscis monkey (Nasalis larvatus) is one of the endemic primates of Borneo; its habitat is limited to riverine forests, mangrove forests, and swamp forests [1]. This monkey is a protected animal under Indonesian government regulations, an endangered species according to the IUCN red list, and is included in Appendix I of the CITES [2]. Most of their habitats are outside protected areas which are prone to damage and changes in function. The proboscis monkey’s habitat has been highly fragmented, and many small populations are isolated. Small populations are very vulnerable to extinction [3].

One of the goals of habitat restoration is to connect fragmented habitats. These activities can be carried out through planting a wide ecological range of species, native species, and required proboscis monkeys [4]. The habitat restoration is in line with implementing the Proboscis Monkey Conservation Strategy and Action Plan 2013-2023, namely the river-bank restoration program.

The ecosystem restoration paradigm is oriented towards biodiversity-ecosystem functioning (BEF) [5]. One targeted function is restoring and repairing wildlife habitats that have been degraded, damaged, or destroyed, directed explicitly at improving habitat conditions for one or more target species [6]. Ecosystem restoration facilitates the re-establishment of the original structure, productivity, and species
diversity close to the initial conditions [7]. Therefore, it is crucial to know the tree species composition and richness in the reference ecosystem as a basis for selecting plant species to be used in restoration activities [8]. Selection of the suitable species will determine the success and functioning of the built target animal habitat. The use of native species is prioritized because they are more effectively used to restore ecosystem function and biodiversity in restored forests [7, 9]. This study aims to determine plant species for proboscis monkey habitat-restoration activities based on reference habitats in East Kalimantan.

2. Methods

2.1. Study Site
The reference habitat locations used in this study were eight proboscis monkey’s habitats in East Kalimantan. A total of six locations (Kuala Samboja, Mahakam Delta, Suwi River, Ohong River, mangrove-Berau Delta, and riverine-Berau Delta) are based on primary data collected from 2011-2019. While the other two in Sungai Wain Protected Forest and Kutai National Park are based on literature (Figure 1).

![Figure 1. Map of study site in East Kalimantan](image)

The description of the proboscis monkey’s habitat is as follows:
- Berau Delta (BD), Berau District (2°10’S 117°44’E). The data was collected in 2019 on the forested mangrove and riverine habitat. Twenty plots of 20 x 20 m were created in mangrove forest (0.8 ha) and 40 plots in the riverine forest (1.6 Ha). Precipitation in the location is 1,845-2,258 mm/year, temperature 27.25-27.91 °C, humidity 82-92%, altitude range from 0-40 m asl, soil types are alluvial and red-yellow podzolic.
- Suwi River (SR), Muara Ancalong Sub District, East Kutai District (0°23’S 116°36’E). The data was taken in 2017 on the 60 plots size 20 x 10 m (1.2 ha). Yearly precipitation in this location is 2,488 mm/year with an average of 207 mm/month, temperature 23.00-31.00 °C, flat topography...
with an altitude range from 0-20 m asl, and soil type is peat.

- Ohong River (OR), Tanjung Isuy Village, Jempang Sub District, West Kutai District (0°27’S 116°8’E). The data was collected in 2016 on the 17 plots size 20 x 20 m (0.7 ha). Yearly precipitation in this location is 2,151 mm/year with an average of 179 mm/month, temperature 26.40-32.90 °C, altitude range from 5-120 m asl, soil types are red-yellow podzolic and sandy.
- Mahakam Delta (MD), Sanga-Sanga and Anggana Sub District, Kutai Kartanegara District (0°34’S 117°21’E). The data was collected in 2019 on the 161 plots 20 x 10 m (3.2 ha). The yearly precipitation is 1,546 mm/year with an average of 128 mm/month, temperature 21.50-34.60 °C, humidity 70-92%, and soil type is alluvial.
- Koala Samboja River (KS), Samboja Sub District, Kutai Kartanegara District (1°0’S 117°6’E). The data was taken in 2011 on the 30 plots 20 x 20 m (1.2 ha). The precipitation is 2,290 mm/year (average 191 mm/month), air temperature ranges from 23.34-34.70 °C, humidity 82-93%, sloping topography, red-yellow podzolic soil, clay, and sandy.
- Sungai Wain Protected Forest (SW), Sub District North Balikpapan Sub District, Balikpapan City (1°10’S 116°50’E). The data base on Noorhidayah et al [10]. The plots were done 63 in sizes 10 x 10 m (0.6 ha). The rainfall in this location is 2.283 mm/year (average 190 mm/month), temperature 24.08-31.24 °C, humidity 80-94%, the topography of 0-150 m asl, the soil types are red-yellow podzolic and alluvial.
- Kutai National Park (KNP), Sangkimah, East Kutai District (0°19’N 117°32’E). The location is a mangrove forest, and habitat data is based on Bismark [11]. One hundred plots were made measuring 20 x 20 m (4.0 ha). Rainfall at the habitat location is 1,543 mm/year, and the average is 128 mm/month, temperature 21.00-34.00 °C, humidity 67-90%, the mangrove area is flat, soil types are alluvial and muddy.

2.2. Methods

The vegetation analysis method used is a line plot transect (Figure 2). The vegetation criteria used are tree-level vegetation (trees; diameter at breast height/dbh ≥ 10 cm) [12]. The data taken were plant species, branch-free height, total height, dbh measured ± 1.30 m from the ground. Plant species that could not be identified in the field were collected leaf samples and further identified at the Herbarium Wanariset (WAN) Samboja, Kutai Kartanegara, East Kalimantan. Identification of the proboscis monkey’s food plant species is carried out directly in the field on an ad-libitum basis and based on the literature [11, 13-20].

![Figure 2. Design of line plot transect.](image)

2.3. Data analysis

Plant species diversity was calculated using the Shannon index \( H' = -\sum_{i=1}^{s} (ni/N) \log (ni/N) \), where \( s \) is the number of species, \( ni \) is the number of trees of species \( i \), \( N \) is the total number of trees of all species, log natural (e) is 2.718 [21].

Vegetation analysis is done by calculating the value of the important value index (IVI), which is the sum of the relative frequency (RF), relative density (RD), relative dominance (RDo) [22].

\[
RF_i = \frac{F_i}{\sum_{i=1}^{s} F_i} \times 100\%
\]
RD\textsubscript{i} = \frac{D\textsubscript{i}}{\sum\textsubscript{j=1}^{I} D\textsubscript{ij}} \times 100\%

RDo\textsubscript{i} = \frac{\sum\textsubscript{j=1}^{I} D\textsubscript{oij}}{D\textsubscript{oi}} \times 100\%

IVI\textsubscript{i} = RFI\textsubscript{i} + RD\textsubscript{i} + RDo\textsubscript{i}

where RF\textsubscript{i} is the relative frequency of species \(i\), RD\textsubscript{i} is the relative density of species \(i\), RDo\textsubscript{i} is the relative dominancy of species \(i\), IVI\textsubscript{i} is the important value index of species \(i\). The frequency (\(F\textsubscript{i}\)) is the intensity of species \(i\) was found at sample plots, density (\(D\textsubscript{i}\)) is the number tree of species per sample plot area, dominancy (\(D\textsubscript{oi}\)) is the basal area of species \(i\) per sample plots area.

Analysis of hierarchical clustering of habitats using the ward. D method. Cluster distance is calculated based on Jaccard's Similarity Index \(SI(x,y) = (|Ix \cap Iy|)/(|Ix| + |Iy| - |Ix \cap Iy|)\), where \(Ix\) and \(Iy\) are the numbers or IVI values of species found on locations \(x\) and \(y\), respectively. The \(|Ix \cap Iy|\) is the numbers or IVI values of species found in both \(x\) and \(y\) [23]. The values used in the analysis are the binary value of the presence of plant species in the habitat (1 = present; 0 = absent) and the IVI of plant species in the habitat; The analysis using software R version 3.4.4 (vegan package).

The approach to the adaptation of plant species in various habitats was analyzed by manually overlaying plant species on habitats in Venn diagrams. Plant species with the most habitat overlays have a high level of adaptation.

3. Results

3.1. The Number of Plant Species

In the sample plots with 11.7 ha in eight proboscis monkey’s habitat locations, at least 152 plant species of woody plants species from 100 genera and 49 families. Of these, 41 species (25.8%) are plant sources of proboscis monkeys (Table 1, Figure 3). The highest species diversity was in the riverine habitat of the Berau Delta (H\textsuperscript{'}=1.25), while the lowest was in the mangrove habitat of the Berau Delta (H\textsuperscript{'}=0.05).

Table 1. Composition of the number of families, genera, plant species, and proboscis monkey’s food sources on the habitat in East Kalimantan.

| All location | BD Riverine | BD Mangrove | SR | OR | MD | KS | SW | KNP |
|--------------|-------------|-------------|----|----|----|----|----|-----|
| Species      | 152         | 68          | 5  | 36 | 24 | 30 | 37 | 8   |
| Food plant   | 41          | 18          | 2  | 17 | 7  | 10 | 11 | 3   |
| Family       | 49          | 35          | 3  | 23 | 17 | 22 | 23 | 8   |
| Genera       | 100         | 56          | 4  | 30 | 22 | 29 | 32 | 8   |
| Sapling area (ha) | 11.7     | 1.6         | 0.8| 1.2| 0.7| 3.2| 1.2| 0.6 |

\(H'\) = 0.54-1.25

Remark: DB = Berau Delta, SR= Suwi River, OR= Ogong River, MD= Mahakam Delta, KS=Koala Samboja, SW= Sungai Wain Protection Forest [9], KNP= Kutai National Park [10].

3.2. Clustering Habitat

The results of the comparison and grouping of habitats show that there are three clusters of habitat types. Clustering based on binary values is more representative of classifying habitat types than IVI values for plant species. The first clustering is mangrove habitat, the second is coastal riverine, and the third is riverine. Clusters using IVI data resulted in riverine forest clusters being closer to mangrove forests. However, based on the plant species, many species were the same as coastal riverine-type habitats (Figures 3a, 3b). However, IVI data and binary data resulted in the same three clusters (Figure 3c).

Mangrove habitat types include Kutai NP and the Berau Delta, Coastal riverine habitat clusters include those in the Mahakam Delta, Wain River, Koala Samboja, and the Berau Delta. While riverine
habitats located far from the sea, namely the Suwi River and Ohong River, are 100 km and 125 km apart from the sea.

![Figure 3](image)

**Figure 3.** Clustering proboscis monkey’s habitat-types in East Kalimantan is based on the binary species presence (a), the important value (b), and analysis of their dendrogram similarity (c).

### 3.3. Structure and Composition

The dominant species can be described by the IVI value. The species and highest IVI for riparian-coastal habitats were Berau Delta (*S. caseolaris*; IVI=82.33%), Mahakam Delta (*Alseodaphne* sp.; IVI=55.17%), Koala Samboja (*S. caseolaris*; IVI=78.03%), Sungai Wain (*Heritiera littoralis*; IVI=103.34%). The riverine habitat in Suwi River is dominated by *Malotus sumatranus* (IVI=106.97%) and Ohong River by *Gluta renghas* (IVI=58.50%). The mangrove habitats in the Berau Delta and Kutai NP are dominated by *Rhizophora mucronata* (IVI=141.52%) and *Rhizophora apiculata* (IVI=239.14%), respectively (Table 2).

### Table 2. The top five tree species with the highest important values index (IVI) in several proboscis monkey’s habitats in East Kalimantan.

| Species                          | RF (%) | RD (%) | RDo (%) | IVI   |
|----------------------------------|--------|--------|---------|-------|
| Berau Delta (Riverine)           |        |        |         |       |
| *Sonneratia caseolaris*          | 11.88  | 11.88  | 58.56   | 82.33 |
| *Brownlowia argentata*           | 11.04  | 11.04  | 6.97    | 29.04 |
| *Syzygium lineatum*              | 9.85   | 9.85   | 4.33    | 24.02 |
| *Syzygium creaghiii*             | 7.64   | 7.64   | 1.96    | 17.24 |
| *Nauclea officinalis*            | 5.77   | 5.77   | 3.36    | 14.90 |
| Mahakam Delta (Riverine)         |        |        |         |       |
| *Alseodaphne* sp.                | 8.00   | 27.05  | 20.12   | 55.17 |
| *Sonneratia caseolaris*          | 13.00  | 10.68  | 23.27   | 46.95 |
| *Cerbera manghas*                | 18.00  | 12.81  | 7.97    | 38.79 |
| *Ficus microcarpa*               | 6.00   | 8.19   | 6.62    | 20.81 |
| *Shirakiopsis indica*            | 7.00   | 7.12   | 5.89    | 20.01 |
| Suwi River (Riverine)            |        |        |         |       |
| *Malotus sumatranus*             | 15.18  | 42.44  | 49.35   | 106.97|

| Species                          | RF (%) | RD (%) | RDo (%) | IVI   |
|----------------------------------|--------|--------|---------|-------|
| Koala Samboja (Riverine)         |        |        |         |       |
| *Sonneratia caseolaris*          | 14.94  | 22.77  | 40.32   | 78.03 |
| *Vitex pinnata*                  | 10.34  | 25.92  | 19.96   | 56.23 |
| *Elaeocarpus stipularis*         | 11.49  | 16.49  | 6.86    | 34.84 |
| *Heynea trijuga*                 | 8.05   | 10.21  | 4.96    | 23.22 |
| *Cerbera manghas*                | 3.45   | 5.50   | 4.13    | 13.08 |
| Sungai Wain PF (Riverine)        |        |        |         |       |
| *Heritiera littoralis*           | 30.23  | 26.88  | 46.23   | 103.34|
| *Cerbera manghas*                | 16.28  | 35.48  | 32.04   | 83.81 |
| *Oncosperma horridum*            | 18.60  | 16.13  | 8.34    | 43.07 |
| *Pouteria obovata*               | 13.95  | 8.60   | 5.62    | 28.18 |
| *Aglaia* sp.*                    | 13.95  | 7.53   | 4.21    | 25.69 |
| Berau Delta (Mangrove)           |        |        |         |       |
| *Rhizophora mucronata*           | 51.14  | 51.14  | 39.24   | 141.52|
### 3.4. Plant Adaptation

The level of species adaptation is seen from the presence of plant species in several locations of habitats. When the species are widely distributed in various locations, they are highly adaptive to various environmental conditions where they grow. The overlay results of plant species in eight habitat locations showed that species distributed in four habitat locations are *Gluta rengas* (BDr, SR, OR, DM), *Vitex pinnata* (BDr, SR, OR, KS), *Sonneratia caseolaris*, and *Cerbera manghas* (KS, SW, DM, BDr). Whereas *Dillenia excelsa*, *Garcinia parvifolia*, *Heritiera littoralis*, and *Ilex cymosa* grew in three habitats. While, *Avicennia alba*, *Carralia brachiate*, *Elaeocarpus stipularis*, *Ficus microcarpa*, *Garcinia littorale*, *Hevea braziliensis*, *Lepisanthes speciosa*, *Malotus sumatranus*, *Peternandra rostrata*, *Sonneratia alba*, and *Vatica rassak* grew in two habitat locations (Figure 4).

Most of these species are also sources of proboscis monkey’s food plant. *Rhizophora apiculata* and *Bruguiera sp.* were found in three mangrove forest types with food plant species are *S. alba*, *A. alba*, and *A. officinalis*. Specifically, *S. caseolaris* is a true mangrove species commonly found in riparian areas because it adapts to low salinity levels.

![Figure 4](image-url)
Protection Forest (SW), Koala Samboja (KS), Kutai National Park (KNP) in East Kalimantan. Plants species presented in the figure are only found on the two or more habitat and food plant species. Asterisk mark shows that proboscis monkey food plant and font size represent overlapping plant species on the habitat.

4. Discussions

Proboscis monkeys have a wide range of coastal areas to inland forests up to 300 km from the sea [24]. This condition causes the proboscis monkeys to have several types of habitats. Generally, the proboscis monkey’s habitat is in the forest, which is still related to water sources, rivers, lakes, seas, and swamps. The monkey’s habitat types include riparian forest, mangrove forest, peat swamp forest [13], freshwater peat swamp [25], and galam swamp forest [26]. In addition, proboscis monkeys are also using mixed Dipterocarp forest habitat [27], heath forest [13], rubber forest, and limestone hill/karst forest [24], which are adjacent to the waters. The wide range of habitats makes the composition of plant species that form the habitat vary; even some habitats have different plant species.

The number of tree species in the proboscis monkey’s habitat ranged from 5-68 species on all study sites. These species need to be selected to be used for habitat restoration. The selection of adaptive species to various soil and environmental conditions will increase the success of rehabilitating the habitat [28]. In addition, the selected plants are proboscis monkey’s feed sources, grow fast, and have known propagation and planting techniques.

Mangrove species are characterized by their muddy habitat and are affected by high salinity. The number of mangrove plant species is relatively less, so that the proboscis monkey food plants are also limited in that habitat. Proboscis monkey’s in mangrove habitats eat the leaves and/or fruit of R. apiculata, A. officinalis, B. gymnorrhiza, and B. parvifolia [11].

The genus Sonneratia (Family Lythraceae) is an essential plant for proboscis monkey. Apart from being a sleeping and activity tree, it is also a food source with high preference. Sonneratia caseolaris grows in areas with low salinity levels, often found in riparian areas relatively far from the sea. Sonneratia alba is more resistant to high salinity, so it is often found in areas directly adjacent to the sea or habitats with high salt concentrations. The pole-level vegetation of S. caseolaris and S. alba often become like bonsai because the shoots are eaten by proboscis monkeys continuously. After all, these species have a high level of preference as a food source.

Vitex pinnata is known as a species that has high adaptation to various types of habitats. This pioneer species can grow well at 400-1 000 m in dry regions in lowland forest habitats, riverbanks, and secondary forests [29]. This species is fast-growing and can survive in open land, so it is recommended to rehabilitate ex-coal mines [28]. Fast-growing species were chosen as one of the requirements for the restoration plant species to form the forest structure quickly. Growth in height and stem diameter at the age of four years of V. pinnata reached 5 m and 7.22 cm, respectively [28]. In addition, proboscis monkeys also have a high preference for using their young leaves as a source of food.

Gluta rengas (Family Anacardiaceae) dominate the trees in the Ogong River habitat. When the local community cuts down other tree species for their wood, only G. rengas remains and becomes a proboscis monkey sleeping tree. Cutting down the G. rengas tree for local people will be fatal for them. The black sap can cause severe allergies to human skin. However, the effect of the sap is not harmful to proboscis monkeys, and they often eat the young leaves. Other Anacardiaceae families are also food sources for proboscis monkeys, such as Buchanania arborescens and Mangifera gedebe. Although this species can grow in several types of habitats and become a source of proboscis monkey food, the process of handling the propagation of seeds is hampered because the sap can cause skin irritation.

The selection of restoration plant species is based on species composition, diversity, and plant adaptation and must be easy to obtain, and the seed propagation technique is known. The dominant species indicated by a high IVI value and ability to grow in various locations showed a high degree of adaptation. While the high value of diversity in a habitat gives many choices of candidate species to choose the best restoration plant. A good plant propagation technique will provide sufficient, inexpensive, and quality plant seedlings. Plant propagation can be done generatively and vegetatively.
The success rate of producing Vitex pinnata seeds generatively reaches about 73% [30], while Sonneratia caseolaris reaches about 75% [31]. The stem cuttings propagation technique can be used for Dillenia excelsa species. Stem cuttings can be used for habitat restoration with extreme water level fluctuations in the swamp and riparian areas. Restoration plants that are submerged for a long time will die. For this reason, Dillenia stem cuttings as high as the highest tide are needed to survive.

5. Conclusion
Proboscis monkey habitat types in East Kalimantan include coastal riparian, riparian, and mangrove. The diversity index in mangrove forests (0.54-0.76) is lower than in riverine forests (0.73-1.25) because of the few species in the mangrove forest, so the limited for chosen for selected restoration plants. The selection of species for habitat restoration is based on its dominance in the habitat, height adaptability, food sources, and the formation of the structure and composition of plant species. The recommended species for riparian habitats are Vitex pinnata, Dillenia excelsa, Garcinia spp., Heritiera littoralis, Ilex cymosa, Cerbera manghas, Hevea brasiliensis, and Sonneratia caseolaris. As for the mangrove habitat using Avicennia alba, R. apiculata, S. alba, A. officinalis, B. gymnorhiza, and B. parvifolia.

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