Land cover and Proboscis monkey habitats in Berau Delta, East Kalimantan

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Abstract. The proboscis monkey is an endangered primate endemic to Borneo. Most of their habitats are outside conservation areas and are under threat from conversion to other land uses, such as those found in the Berau Delta. Habitat loss and destruction significantly affect the quality and viability of the proboscis monkey population. This study aims to determine land cover and proboscis monkey habitat types in Berau Delta. Land cover was obtained from the interpretation of the Lanskit 8 OLI 2019 satellite image. Vegetation data were collected using a line plot transect method and continued with cluster analysis. The results showed that mangrove forest has the largest coverage (35.92%), followed by secondary forest (17.10%) and riparian forest (12.96%). At least 74 species of woody plants belonging to 61 genera and 37 families in a 2.4 ha observation plot. The range of species diversity index was from 0.80 to 2.88, and; evenness index values range from 0.58 to 0.82. The habitat was categorized into two main clusters: mangrove cluster (Buasin Cape, Guntung Estuary) and riverine cluster (Lati River, Saodang Kecil Island, Batu-Batu, Bebanir Lama). The mangrove forest habitat consists of Rhizophora mucronata, R. apiculata, Bruguiera sp, Sonneratia alba, and Avicennia alba. The riparian habitats are dominated by Sonneratia caseolaris, Vitex pinnata, Cerbera manghas, Brownlowia argentata, Heritiera littoralis, Syzygium lineatum, Nauclea officinalis, Xylocarpus granatum, Syzygium sp.1, and A. alba. The average of total and lower branches height of trees in the Lati River and Basin Cape were higher than in other habitats, forming a continuous canopy.

1. Introduction

The proboscis monkey (Nasalis larvatus) is one of the primate species of the Colobinae sub-family, which is endemic to Borneo. The proboscis monkey occupies several types of habitats, each with different characteristics; mangrove, swamp, and riparian forests [1]. These habitats, however, are undergoing rapid conversion. Mangrove forests have a high fishery potential so that many of them are being converted into fishponds. In contrast, riparian forests are being converted the fastest because of their easy accessibility by river transportation [2]. Indeed, riparian habitats are under pressure due to conversion into residential areas, fields, and oil palm and cocoa plantations [1]. Habitat destruction is also caused by forest fires [3] and various river pollutants [2].

Habitat loss and destruction significantly affect the quality and viability of the proboscis monkey population. The habitat loss rate is estimated at 2% per year [4]; currently only 55% of the original 121,670 km² proboscis monkey habitat remains. Eleven percent of its habitat is located in conservation...
areas [5] and only 9% of is in protected areas [6]. The destruction of their habitat can result in habitat fragmentation and isolated populations in small areas. Small populations have a high potential for extinction due to inbreeding pressure [7]. This paper aims to identify land cover conditions, vegetation types, and characteristics of the proboscis monkey habitat in the Berau Delta.

2. Methods

2.1. Study site
Observations were conducted from Augustus to December 2019 in Berau Delta, East Kalimantan, Indonesia. The study area covers an area of interest (AOI) of 911.21 km² consisting of six locations where vegetation analysis was conducted: a narrow river (Lati River), a wide river (Batu-Batu), a small island (Saodang Kecil Island), coastal habitats (Buasin Cape and Guntung Estuary), and a mixed habitat, (Bebanir Lama). The farthest of these habitats extended 1,810m inland from the riverbank, representing the monkey’s maximum daily range [8].

2.2. Land cover
Land cover was delineated based on Lansat 8 OLI Path 116 Row 59 images acquired on July 15, 2019 (https://earthexplorer.usgs.gov/). Before interpretation, the image was radiometric and atmospheric corrected, pan-sharpening using the panchromatic band with 15 m resolution. Delineation was carried out in potential proboscis monkey habitats: (mangrove/swamp forest, riverine forest, secondary forest), buffering habitats (scrub, swamp, garden/field), and non-habitat (open areas, roads, settlements, ponds/water canals, mining/industry). The interpretation results were then verified through ground checking.

2.3. Vegetation analysis
Vegetation data was collected using a line plot transect method. Each location is made of two paths, namely a line perpendicular to the riverbank and parallel to the riverbank. The first transect was made to determine the variation of plant species from the riverbank into the forest. The second transect was to determine species variation along the riverbank, considering that many proboscis monkeys use sleeping trees on the riverbanks and as a place for their activities. The whole transect is 1.20 km, with a sample area of 2.40 ha. The transect is divided into 20 x 20 m plots to record tree levels (trees; dbh>20 cm) and small trees (pole; ≥10 cm dbh <20 cm), nested there are 5 x 5 m sub-plots for sapling level (dbh <10cm, height> 1.5m) [9]. Data collection focused on plant species, lower branch height, total height, and diameter at breast height (dbh). Plant species were identified at the Herbarium Wanariset Samboja (WAN). Scientific nomenclature refers to http://theplantlist.org/. Plant types found were tabulated and sorted according to the family, genus, and species.

2.4. Data analysis
Plant diversity was calculated using the Shannon index ($H'$) [10] and the Evenness Index [11]. Vegetation data is calculated as the importance value index (IVI), which is the sum of relative frequency (Rf), relative density (Rd), relative dominance (Rdo) [12]. Community habitats similarity was analyzed using the Jaccard Index [13]. Hierarchical clustering between habitats was analyzed using R software version 3.4.4 with “vegan” packages. The data used was binary data (1 = found, 0 = not found). The cluster spacing used the Jaccard method, while the habitat cluster used the ward.D method.

3. Results and Discussion

3.1. Land cover
The Lansat image interpretation and ground checking identified eleven land cover types in the Berau Delta (Table 1). Mangrove forest/swamp has the highest percentage (35.92%), followed by secondary forest (17.10%) and riparian forest (12.96%). Most of the mangrove forests are located in coastal areas. Most of the mangrove forests on the large islands of the Berau Delta have been primarily
converted into ponds. There are more than 11 thousand hectares of ponds in the Berau Delta, and it is expected that the conversion will continue as evidenced by field observations that found mangrove areas being prepared for conversion to fish ponds. Riparian forests are generally located along the banks of major rivers and creeks. The partially riparian forest has been fragmented into settlements, roads, fields, plantations, industry, and mining. Meanwhile, secondary forest is located in areas not affected by tides and in an ecotone area behind riparian forests (Figure 1).

Table 1. Land covers of Berau Delta

| Land covers          | ha     | %    |
|----------------------|--------|------|
| Mangrove/Swamp       | 32,734.15 | 35.92 |
| Secondary forest     | 15,578.47 | 17.10 |
| Riverine forest      | 11,811.33 | 12.96 |
| Pond/water canal     | 11,530.12 | 12.65 |
| Shrubs               | 5,983.81  | 6.57  |
| Swamp scrub          | 4,983.67  | 5.47  |
| Garden/Field         | 2,857.34  | 3.14  |
| Open area            | 2,480.45  | 2.72  |
| Settlemaker          | 1,856.90  | 2.04  |
| Road                 | 810.90   | 0.89  |
| Mining/industrial area | 494.19  | 0.54  |
| **Total**            | 91,121.33 | 100   |

Figure 1. The land cover of proboscis monkey habitat in Berau Delta

3.2. Plant diversity

Based on an analysis of the data, at least 74 species of woody plants belonging to 61 genera and 37 families in the observation plot. The species diversity index ranged from 0.80 to 2.88; the highest index value was in the riparian habitat Bebanir Lama, while the lowest index was in the mangrove
habitat Guntung estuary. Evenness index values range from 0.58-0.82 (Table 2). The high index value indicates that the number of trees in each species is relatively the same in the habitat.

**Table 2.** Vegetation profile at six sampling sites in proboscis monkey habitats in Berau Delta

| Parameter          | Riverine | Mangrove |
|--------------------|----------|----------|
|                    | Lati River | Saodang Kecil Island | Batu-Batu | Bebanir Lama | Guntung Estuary | Buasin Cape |
| Density (trees/ha) | 513      | 348      | 383      | 295     | 478       | 505      |
| Number species     | 24       | 8        | 14       | 33      | 4         | 4        |
| H'                 | 2.39     | 1.33     | 2.07     | 2.88    | 1.03      | 0.80     |
| Hmax               | 3.18     | 2.08     | 2.64     | 3.5     | 1.39      | 1.39     |
| Evenness Index     | 0.75     | 0.64     | 0.78     | 0.82    | 0.74      | 0.58     |

3.3. **Habitat clustering**

In general, the community similarity index in the proboscis monkey habitat in the Berau Delta ranges from 0-60%. In general, the community similarity index in the proboscis monkey habitat in the Berau Delta ranges from 0-60%. The habitats in Buasin Cape and Guntung Estuary have a high plant community similarity of 60%; meanwhile a comparison of the habitat of Saodang Kecil Island with Guntung Estuary and Buasin Cape with Batu-Batu, found no similarities at all. The proboscis monkey habitat is divided into two main clusters, namely: cluster mangrove (Buasin Cape, Guntung Estuary), and cluster riverine (Lati river, Saodang Kecil Island, Batu-Batu, Bebanir Lama) (Figure 2).

![Cluster Habitat](image)

**Figure 2.** The cluster of proboscis monkey habitat is based on the Jaccard similarity index.

3.4. **Structure and composition**

3.4.1. **Mangrove forest.** The mangrove forest habitats are Buasin Cape and Guntung Estuary, formed by *Rhizophora mucronata, R. apiculata, Bruguiera sp, Sonneratia alba,* and *Avicennia alba* (Table 3).
### Table 3. The floristic composition in mangrove forests on the tree, poles, and saplings stages

| Species                      | Busain Cape | Guntung Estuary |
|------------------------------|-------------|-----------------|
|                              | Rf (%)      | Rd (%)          | Rdo (%) | IVI (%) | Rf (%) | Rd (%) | Rdo (%) | IVI (%) |
| **Trees**                    |             |                 |         |         |        |        |         |         |
| Rhizophora mucronata         | 50.0        | 73.2            | 74.0    | 197.2(1)| 14.3   | 7.1    | 5.0     | 26.5(3) |
| Rhizophora apiculata         | 35.7        | 22.0            | 23.2    | 80.9(2) | -      | -      | -       | -       |
| Bruguiera sp.                | 7.1         | 2.4             | 1.5     | 11.0(3) | -      | -      | -       | -       |
| Sonneratia alba              | 7.1         | 2.4             | 1.3     | 10.9(4) | 21.4   | 20.2   | 24.0    | 65.6(2) |
| Avicennia alba               | -           | -               | -       | -       | 64.3   | 72.6   | 71.0    | 207.9(1)|
| **Poles**                    |             |                 |         |         |        |        |         |         |
| Bruguiera sp.                | 39.1        | 61.5            | 62.1    | 162.7(1)| -      | -      | -       | -       |
| Rhizophora apiculata         | 39.1        | 34.2            | 32.6    | 105.9(2)| 5.3    | 2.8    | 3.4     | 11.4(4) |
| Rhizophora mucronata         | 21.7        | 4.4             | 5.3     | 31.3(3) | 36.8   | 61.5   | 58.1    | 156.4(1)|
| Avicennia alba               | -           | -               | -       | -       | 42.1   | 30.3   | 32.9    | 105.3(2)|
| Sonneratia alba              | -           | -               | -       | -       | 15.8   | 5.5    | 5.6     | 26.9(3) |
| **Saplings**                 |             |                 |         |         |        |        |         |         |
| Rhizophora mucronata         | 33.3        | 55.9            | 63.93   | 153.2(1)| 57.1   | 79.0   | 66.8    | 202.9(1)|
| Rhizophora apiculata         | 27.8        | 17.8            | 29.18   | 74.8(2) | 14.3   | 4.8    | 10.8    | 29.9(4) |
| Xylocarpus granatum          | 16.7        | 11.9            | 1.01    | 29.5(3) | -      | -      | -       | -       |
| Sonneratia alba              | 11.1        | 11.9            | 4.52    | 27.5(4)| 14.3   | 11.3   | 11.6    | 37.2(2) |
| Bruguiera sp.                | 11.1        | 2.5             | 1.35    | 15.0(5)| -      | -      | -       | -       |
| Avicennia alba               | -           | -               | -       | -       | 14.3   | 4.8    | 10.9    | 30.0(3) |

Remarks: Rf= Relative frequency; Rd= Relative density; Rdo= Relative dominance; IVI=Important Value Index; The numbers in parentheses indicate the grade by important value index (IVI).

3.4.2. Type Riparian. The riparian forest habitat cluster is Lati River, Batu-Batu, Saodang Kecil Island, and Bebanir Lama. The Lati River represents the habitat on the banks of a small river, Saodang Kecil Island represents an island habitat, while Batu-Batu represents habitat on the banks of a major river.

### Table 4. The top five of tree, pole, and saplings stages with the highest IVI were in riparian forest

| Location/Species          | Tree       | Pole       | Sapling    |
|---------------------------|------------|------------|------------|
|                           | FR         | KR         | DR         | IVI        | FR         | KR         | DR         | IVI        |
| Bebanir Lama              |            |            |            |            |            |            |            |            |
| Xylocarpus granatum       | 16.0       | 23.1       | 16.8       | 55.9(1)    | 10.3       | 17.7       | 27.0       | 55.0(1)    | 6.3        | 10.5       | 14.1       | 30.8(2)    |
| Syzygium sp.1             | 8.0        | 7.7        | 20.4       | 36.1(2)    | -          | -          | -          | -          | -          | -          | -          | -          |
| Avicennia alba            | 8.0        | 15.4       | 11.4       | 34.8(3)    | -          | -          | -          | -          | -          | -          | -          | -          |
| Rhizophora apiculata      | 8.0        | 12.8       | 7.4        | 28.2(4)    | 7.7        | 8.9        | 9.5        | 26.0(3)    | -          | -          | -          | -          |
| Koompassia excelsa        | 4.0        | 2.6        | 21.4       | 28.0(5)    | -          | -          | -          | -          | -          | -          | -          | -          |
| Sonneratia caseolaris     | -          | -          | -          | -          | 2.6        | 21.5       | 13.6       | 37.7(2)    | -          | -          | -          | -          |
| Rhizophora mucronata      | -          | -          | -          | -          | -          | 2.6        | 8.9        | 7.0        | 18.4(4)    | -          | -          | -          | -          |
| Syzygium lineatum         | -          | -          | -          | -          | -          | 7.7        | 5.1        | 4.8        | 17.6(5)    | 6.3        | 7.0        | 8.9        | 22.2(3)    |
| Fordia splendidissima     | -          | -          | -          | -          | -          | -          | -          | -          | -          | 10.4       | 18.6       | 20.4       | 49.5(1)    |
| Aquilaria beccariana      | -          | -          | -          | -          | -          | -          | -          | -          | -          | 6.3        | 4.7        | 7.0        | 17.9(4)    |
| Baccaraea tetrandra       | -          | -          | -          | -          | -          | -          | -          | -          | -          | 4.2        | 2.3        | 7.8        | 14.3(5)    |
| Lati River                |            |            |            |            |            |            |            |            |            |
| Sonneratia caseolaris     | 13.9       | 20.5       | 55.2       | 89.6(1)    | -          | -          | -          | -          | -          | -          | -          | -          |
| Syzygium lineatum         | 11.1       | 28.8       | 12.8       | 52.7(2)    | 11.8       | 19.7       | 21.7       | 53.2(2)    | 11.1       | 20.0       | 6.7        | 37.9(3)    |
| Nauclea officinalis        | 16.7       | 20.5       | 11.6       | 48.8(3)    | 13.7       | 14.4       | 15.9       | 44.0(3)    | 7.4        | 4.4        | 8.2        | 20.1(4)    |
| Heritiera littoralis       | 8.3        | 4.1        | 3.1        | 15.6(4)    | 7.8        | 3.0        | 3.8        | 14.6(5)    | -          | -          | -          | -          |
Tree species in riparian habitats are dominated by *Sonneratia caseolaris*, *Vitex pinnata*, *Cerbera manghas*, *Brownlowia argenteata*, *Heritiera littoralis*, *Syzygium lineatum*, *Nuclea officinalis*, *Xylocarpus granatum*, *Syzygium sp.*, and *Avicennia alba*. Poles stage is dominated by *Oncosperma horridum*, *Symphlocos celastrifolia*, *V. pinnata*, *H. littoralis*, *B. argenteata*, *S. caseolaris*, *Syzygium creaghi*, *S. lineatum*, *N. officinalis*, *X. granatum*, and *Rhizophora apiculata*. The sapling stage is dominated by *Glochidion littorale*, *Ardisia elliptica*, *Croton oblongus*, *B. argenteata*, *H. littoralis*, *Disoolxym arborescens*, *S. creaghi*, *Barringtonia conoidea*, *S. lineatum*, *Fordia splendidissima*, and *X. granatum* (Table 4). Generally, no seedlings were found in the observation plots in the Lati River and Batu-Batu habitat because the riverbanks were often inundated with water. The land area was cover by shrubs, such as *Acroticum aureum*, *Etilgera sp.*, *Lygodium sp.*, *Pothos sp.*, *Scleria sp.*, *Adenia sp.*, *Pandanus sp.*, *Flagelaria sp.*, and *Derris sp.* Meanwhile, the forest floor on Saodang Kecil Island was mostly tightly closed by *Acanthus illicifolius*.

**3.5. Trees strata**

The average of total and lower branches height of trees in the Lati River and Buasin Cape were higher than in other habitats and formed a continuous canopy. Meanwhile, the average tree diameter and basal area in Saodang Kecil Island and Muara Guntung were higher relatively but with a discontinuous canopy. Trees in Batu-Batu clustered on land formed by watercourses so that the canopy that forms can create gaps between tree clusters. In general, tree species on river banks are relatively more diverse with lower canopy heights than those farther from the riverbanks. The habitat in Bebanir Lama is a riparian forest and a small part of the mangrove forest. The leaves and shoots of *Sonneratia alba*, which grow on the riverbanks, are the main food source for the proboscis monkeys. The leaves are continuously eaten by monkeys so that the *S. alba* tree conditions become dwarfed.
3.6. Discussions

The proboscis monkey’s habitat in the Berau Delta consists of two types of habitat: mangrove forests in the coastline and riparian forests, which are relatively far from the coast. Their habitat is not only found in coastal wetlands but is also found living far on land 250-300 km inland from the coast [14]. Although they are far from the coast, their habitats are still associated with waters [15], such as rivers, swamps, and lakes. Apart from living in mangrove and riparian forests, proboscis monkeys are also reported to live in peat swamp forests [16]; [17], freshwater peat swamp forest [18], galam swamp forest [3], mixed Dipterocarp forest [19], kerangas forest [16], rubber forest and limestone/karst forest [20].

Their habitat in the Berau Delta is geomorphologically similar to the Mahakam Delta habitat, which is both fertile areas formed by silt from large river flows [2]. The Berau Delta is the estuary of the Berau River (292 km), which is the main river of the Segah River (152 km) and the Kelay River (254 km), while the Mahakam Delta is the estuary of the Mahakam River (980 km). Proboscis monkeys can be found from the mouth of the river and along the river banks. The river is a transportation route in Kalimantan, which is the source of many threats and disturbances, including hunting, industrial development, and fisheries [21].

Proboscis monkeys prefer the riparian habitat type in the Berau Delta. This habitat is supported by a higher plant species richness than other habitat types. The richness of plant species in riparian habitats occurs due to several reasons. First, the habitat’s location is in an intermediate area between the wetlands on the riverbank and the dry land, which forms an ecotone area with a combination of the two types of forest. Second, the frequency of flooding and altitude also affects the richness of plant species in riparian forests. Riparian forests with regular flooding have high plant species richness and species that are more tolerant of their habitat’s resilient conditions [22], that is, they can adapt to food conditions. Third, the distribution and abundance of plant species are also related to topographic variations. The riparian habitat is significantly richer in plant species than montane forest and hill forest [23].

Proboscis monkeys are arboreal primates meaning that most of their time is spent in the trees. The ideal habitat for proboscis monkeys is to have an interconnected canopy where there are many trees of large diameters and branches, such as along the Lati River and in Buasin Cape. In contrast, other riverbank habitats have been fragmented and converted into fishponds, settlements, coal mining facilities, and docks. These conditions create forest gaps that are too far away and will be challenging to jump over, so the proboscis monkeys have to come down to the ground to move between patches of habitat. Large trees are needed to support their relatively large bodyweight of the proboscis monkeys compared to several other Colobinae subfamilies. Adult male proboscis monkeys can weigh up to 22.5 kg, while females can weigh 11.0 kg [24]. Proboscis monkeys often break trees when they jump or move and cause monkeys to fall from trees and suffer injuries. The examination of several specimens of proboscis bones in the museum showed many fracture marks [25].

Large and tall trees on the river banks are essential for the proboscis monkeys because their daily routine generally brings them back to the riverbank’s sleeping trees in the late afternoon [2]. The selection of sleeping trees by the river is a strategy to; avoid land predators [26], seek out conducive

### Table 5. The tree stands condition of several proboscis monkey’s habitat type in Berau Delta.

| Parameter                  | Riverine | Mangrove |
|----------------------------|----------|----------|
| Height (x+SD)(m)           | Lati      | Guntung  |
|                            | 14.5±4.9 | 9.7±4.0  |
| Range                      | 6-26     | 5-23     |
| TBC (x+SD)(m)              | Saodang  | Buasin   |
|                            | 6.6±3.2  | 4.8±3.2  |
| Range                      | 1.5-18   | 0.15-18  |
| dbh (x+SD)(cm)             | Batu     | 21.5±7.4 |
|                            | 21.1±12.9| 19.3±15.1|
| Range                      | 10-85    | 10-95    |
| Basal area (m²/ha)         | Bebanir  | 10-40    |
|                            | Lama     | 11.3     |
| Canopy                     | Guntung  | 19.4     |
|                            | Estuary  | 5.1      |
|                            | Buasin   |          |

### Continue

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temperatures, allow for easier foraging [27], enhance social communication between groups [28], and allow for efficiency in movement [29].

Proboscis monkeys generally prefer sleeping trees that are close to the river bank (5-35 m), consisting of large trees (height, diameter, the diameter of the lowest branches) with primary branches connected to the surrounding trees, and dense undergrowth [30]. Sleeping trees also have branches closest to the opposite river bank, so that if there is a threat from land predators, they can quickly jump to the other side of the river [26] [31]. Several of proboscis monkey groups often use sleeping trees close to each other, and even two groups use the same sleeping tree. This behavior reflects an effort for them to cooperate to protect against potential [17].

The different habitat types provide different food plants [32]. Proboscis monkeys eat not only the leaves and plants fruits [33] but also flowers, seeds [34], bark, crabs [35], small animals [36], insects [16], and termites of the Microcerotermes distans species [21]. The diversity of plant species in riparian forests provides various food plants for the proboscis monkeys. The monkeys consume several plants to balance nutrients, where the nutrients that are not contained in certain plants will be fulfilled from other plants [37]. The quality and quantity of feed needs will vary depending on species, sex, age, physiological function, season, weather, and geographical conditions [38]. The primary food sources for proboscis monkeys in the Berau Delta are the leaves of Sonneratia caseolaris and S. alba. S. caseolaris species are more common in riparian habitats, which are relatively far from the coastline with lower salinity levels, such as in the areas of Lati River, Besing Island, Batu-Batu, Perangat Cape, and Saodang Kecil Island. Sonneratia alba is mostly in tidal areas with high salinity, such as in Semanting Bay, Guntung Estuary, Radak, and Bebanir Lama.

4. Conclusion
Proboscis monkeys generally inhabit two types of forest, riparian and mangrove. Both forest types are relatively dominant in the Berau Delta. The diversity of plant species in the habitat provides a source of food, while the vegetation's structure and composition support the monkeys' movement and daily activities.

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