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Submission date: 16-May-2023 07:16AM (UTC+0700)

Submission ID: 2094175927

File name: 7928-Article_Text-47024-1-10-20210803.pdf (1.16M)

Word count: 6943

Character count: 36365

Mangrove diversity and community structure of Mimika District, Papua, Indonesia

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Manuscript received: 7 February 2021. Revision accepted: 30 July 2021.

Abstract. Setyadi G, Pribadi R, Wijayanti DP, Sugianto DN. 2021. Mangrove diversity and community structure of Mimika District, Papua, Indonesia. *Biodiversitas* 22: 3562-3571. Despite being one of the largest mangrove forest in the world, there are few studies on mangrove diversity and community structure in Mimika, Papua Province. The study collected data from 4 estuaries of Mimika Region, i.e. Kamora, Tipuka, Ajkwa and Minajerwi. Mangrove species, tree diameter at breast height and canopy height data were collected in 10 m x 10 m plot with three replicates for distance, specifically 0, 250, and 500m perpendicular to the riverbank. This study found 66 mangrove species consisting of 20 major, 10 minor, and 36 associate mangrove species. Their density ranged from 577-1,345 trees ha⁻¹ with diversity Shannon-Weiner diversity indices (H') ranging from 0.62-1.19 and Evenness Index (J') ranging from 0.09-0.18. The canopy height of the mangrove trees was ranged from 9-42.5 m. The highest density species was *Rhizophora apiculata* (333 ha⁻¹) followed by *Avicennia marina*, *Bruguiera gymnorhiza*, and *Camptostemon schultzei*, while *B. parviflora*, *S. alba*, and *X. granatum* were the least dominant. Regarding basal area, *R. apiculata* and *B. gymnorhiza* were the highest with medians of 7,853 cm² ha⁻¹ and 5,201 cm² ha⁻¹ respectively. In the low tidal zone area, mangrove was dominated by *A. marina*, *Sonneratia alba* and *R. mucronata*. Medium low to medium high tidal zones were dominated by *B. gymnorhiza*, *R. apiculata*, and *B. parviflora*. The high tidal zone was more dominated by *Nypa fruticans*.

Keywords: diversity, density, mangrove, Mimika, Papua, stratification, species richness

INTRODUCTION

The mangrove forests of Indonesia are among the most species-rich and extensive in the world, representing around 20-23.5% of the world's total mangrove area (Giri et al. 2011; Ilman et al. 2011). There are various assessments of the total area of Indonesia's mangrove forests ranging from 2.4-7.8 million ha (Kusmana 2015; Rizal et al. 2018). The majority of Indonesia's mangrove forests are found in Papua (58%), Kalimantan (16%) and Sumatra (19%) with the rest found in Sulawesi, Java, and Maluku (Hanum et al. 2014).

According to Hogarth (2015), true mangroves comprise 70 species belonging to 20 families in which 47 species represent the major component (true, strict, or exclusive mangrove species). In Indonesia, Rizal et al. (2018) have recorded 89 species, 35 being trees. Hanum et al. (2014) report finding 202 mangrove species in Indonesia consisting of 43 true mangrove species and the remaining mangrove associates. About 166 species were found in Java, 157 in Sumatra, 150 in Kalimantan, 142 in Papua, 135 in Sulawesi, 133 in Maluku, and 120 species in the Lesser Sunda Islands.

Most mangrove diversity and distribution studies in New Guinea have been carried out in Papua New Guinea (Shearman 2010). It is estimated that Papua New Guinea

contains 592,900 ha of mangroves, which are distributed along the coastal provinces (Shearman et al. 2009). In Papua, Indonesia, there is an estimated 1.4-1.6 million ha of mangroves, making the country home to one of the largest mangrove areas in the world (Hanum et al. 2014; Rizal et al. 2018). Based on data from the Ditjen PDASHL, Ministry of Environment and Forestry, Republic of Indonesia (2019), there are 1,497,724 hectares of total mangrove area in the provinces of West Papua and Papua.

Mimika District is located in the southern part of Papua. This district has a complete landscape from mangroves in coastal areas, peat swamp forests, lowland forests, and mountainous areas through to icy alpine zones. The estimated mangrove area of Mimika is 186,291 ha (Aslan et al. 2018). Several studies have been carried out in the area on topics such as the distribution of carbon stock (Taberima et al. 2017), the history of sediment and trace element deposition in the Ajkwa River and the Holocene palynology of Mimika (Brunskill et al. 2004; Ellison 2005), and the mapping of the distribution, biomass, and mangrove canopy of Mimika using remote sensing (Aslan et al. 2018). However, research on mangrove forests in Papua, particularly along the southern coast and in Mimika is limited. With its vast mangrove area, the province of Papua in Indonesia is probably the most pristine and diverse mangrove forest in the world, with just 29-32

obligate taxa of mangrove flora being recorded in Papua New Guinea (Johnstone and Frodin 1982). Given the above, this study aims to determine the species richness and density of mangrove vegetation in four estuaries in Mimika District, describe vegetation composition, structure, and Species Importance Value, and determine mangrove stratification based on tidal zones in the area. The results of this study will provide a better understanding of the mangrove ecosystem in Mimika, most of which is classified as a Protected Forest under the Ministry of Forestry, Republic of Indonesia, Decree SK.782/Menhut-II/2012.

MATERIALS AND METHODS

Study area

The mangrove forest in four estuaries in Mimika District, Papua, Indonesia, i.e., Kamora, Tipuka, Ajkwa, and Minajerwi Estuaries, were selected for study. The forest covers an area of 600 km². The geographic positions of the sampling locations are presented in Table 1 and Figure 1. The four estuaries drain large catchments that extend to the 3000–4,500 m mountain crests. The catchments receive extremely high volumes of annual rainfall (4–13 m yr⁻¹; Setyadi et al. 2009). The mangrove forest community extends about 20 km inland from the coastline. The estuaries are considered to contain high hydraulic energy due to rainfall magnitudes and the 3.3–3.6 m tidal ranges (Aslan et al. 2018).

Procedures

Nine locations were surveyed: three in the Kamora Estuary, two in the Tipuka Estuary, three in the Ajkwa

Estuary and one in the Minajerwi Estuary (Table 1). Sampling was conducted in March 2019. Analysis of the structure and composition of mangrove vegetation was carried out using the line transect plot method (Mueller-Dombois & Ellenberg 1974). At each location, mangrove tree data were collected at 0, 250, and 500 m perpendicular to the riverbank (Figure 2). At each of sublocations, mangrove trees were surveyed in triplicates of 10 m x 10 m quadrants (Pribadi 1998; Ganivet & Bloomberg 2019). Since mangrove trees have a unique shape and growth form which sometimes creates difficulties in deciding where to measure the diameter, a recommendation by Cintron & Novelli (1984) will be applied, where each branch (dbh ≥ 10 cm) will be measured at 1.3 m above the ground level. The species found in each plot was identified and classified taxonomically using classification from Hogarth (2015). Three height was measured by using clinometer and laser distance meter which are considered as very accurate to measure tree height (William et al. 1994).

Table 1. Coordinates mangrove sampling locations in Mimika Region, Papua, Indonesia

Station	Location	Latitude (S)	Longitude (E)
TIP-1	Tipuka Estuary	4°45'32.5"	136°51'48.9"
TIP-2	Tipuka Estuary	4°47'10.9"	136°51'16.9"
KAM-1	Kamora Estuary	4°47'51.7"	136°41'58.1"
KAM-2	Kamora Estuary	4°48'00.6"	136°41'06.2"
KAM-3	Kamora Estuary	4°49'09.2"	136°41'01.2"
AJK-1	Ajkwa Estuary	4°51'15.8"	136°53'31.2"
AJK-2	Ajkwa Estuary	4°53'53.8"	136°52'08.2"
AJK-3	Ajkwa Estuary	4°55'12.1"	136°50'07.3"
MIN-1	Minajerwi Estuary	4°55'17.8"	137°00'54.6"

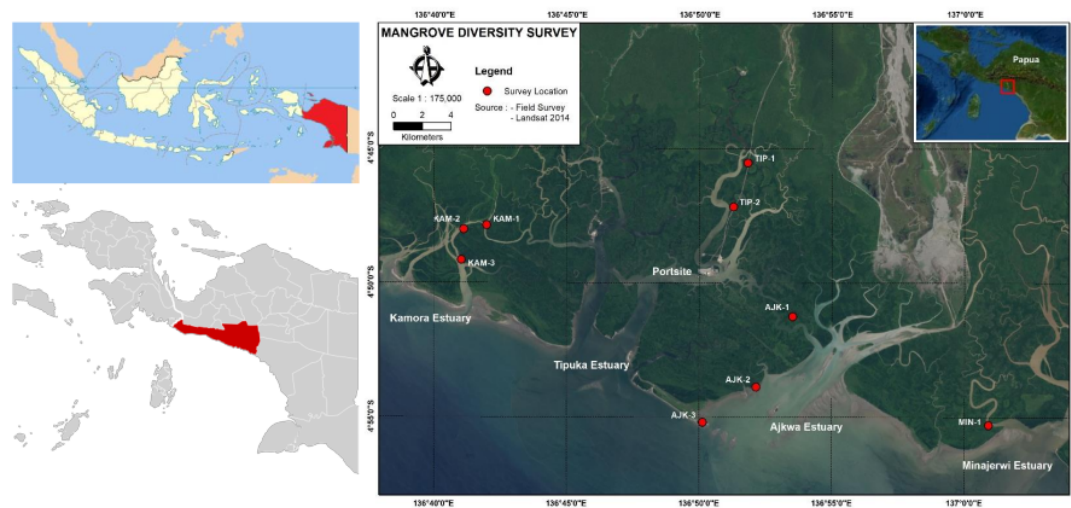


Figure 1. Study area in Mimika District, Papua, Indonesia, and sampling locations of the four estuaries

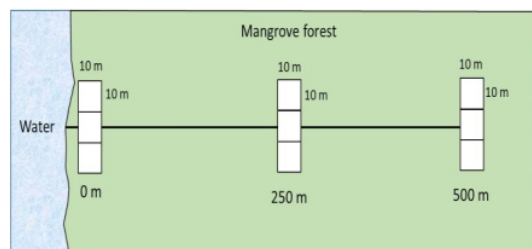


Figure 2. Line transect plot at each sampling location

Additional qualitative vegetation data was carried out in June 2020 to determine mangrove zonation from low tidal zone area down to coastline along the Tipuka and Ajkwa Estuaries. Every approximately 2 km, rapid assessment on the most dominant species was recorded at 20 x 20 plots (Ganivet & Bloomberg 2019). Photos of the flora, tree height, and estimation of canopy cover were also recorded.

Data analysis

The vegetation data was analyzed using the method provided by Lavaisha and Mangora (2016), which includes relative frequency (RF), relative density (RD), and relative dominance (RDo). The Species Importance Values (SIV) of each species were determined by adding together the respective relative frequency, relative density, and relative dominance. The relative dominance of a species is measured according to how often it occurs, its numbers, and the area it occupies in a community. Species diversity was estimated using Shannon-Wiener Index (H') and Evenness (J') (Shannon & Wiener 1993) as follows.

$$H' = - \sum_{i=1}^R p_i \ln p_i$$

Where: H' = Shannon-Wiener Index of Diversity, $p_i = n_i/N$, where n_i = total number of individuals of species i in the quadrat/sample and N = total number of individuals of all the species in the quadrat/sample. According to Odum and Barret (2004) the Shannon-Wiener diversity index is classified into three levels: low ($H < 2$), moderate ($2 < H < 4$), and high ($H > 4$).

The evenness (J'), a measure of the equitability of species abundances, was derived using H' where S is the total number of species. The evenness value of 0.6 - 1 is classified as high, the value of 0.4 < J' < 0.6 is moderate and for values 0 - 0.4 is low (Krebs 1989). Below is the quotation (Pielou 1975):

$$J' = \frac{H'}{\ln S}$$

The classification of mangrove zones was determined by the elevation of and duration of inundation for each plot. Elevation data was obtained using Light Detection and

Ranging (LIDAR), while the duration of inundation was calculated using the 2019 Tidal Table provided by PUSHIDROSAL (Indonesian Navy Hydrographic and Oceanographic Center). Four classifications were established (Tusinski and Verhagen 2014): low tidal zone (<0.5m); medium-low tidal zone (0.5-1.5m); medium-high tidal zone (1.5-2 m); and high tidal zone (>2 m). The density data of each plot was used to determine the mangrove vegetation included in each classification.

RESULTS AND DISCUSSION

Species richness and densities

Fifteen mangrove species were observed in the plot area. Additional data collected from the adjacent transect plot found a total of 66 species comprising 20 species of major mangrove components, 10 species of minor components, and 36 species of mangrove associates (Table 2). Classification was based on Hogarth (2015).

The density, Shannon-Wiener diversity index (H'), and evenness index (J') of the mangrove trees surveyed are shown in Table 3. Based on the data, the density of the mangrove trees in the study area ranged from 577-1,345 trees ha^{-1} (average 773 trees ha^{-1}). Although the tree density of station AJK-3 in the Ajkwa Estuary was 2.3 times higher than that of Station KAM-2 in the Kamora Estuary, this was not a significant difference, as indicated by the overlapping standard deviations. The high diversity found in the Ajkwa Estuary is due to the mangrove succession process prevalent in the area caused by wave action and sedimentation. Due to its position in the seaward margin, the vegetation was denser but smaller in diameter.

The table above reveals that the Shannon-Wiener diversity index (H') for the mangrove trees in the study area ranged from 0.62-1.19, which is categorized as low. The highest diversity index was recorded for AJK-3 in the Ajkwa Estuary and the lowest for MIN-1 in the Minajerwi Estuary. AJK-3 is located in a low tidal zone where natural succession and new colonization occur particularly along the edge of the mangroves (0 m). Here, pioneer species such as *A. marina* and *S. alba* are dominant. However, other species commonly found in the medium tidal zone were also found in the low tidal zone at a higher elevation of 500 m, such as *R. apiculata*, *B. parviflora*, *B. gymnorhiza*, and *L. littorea*. The wide range in elevation at one location might be the cause of higher diversity. As the key of mangrove adaptations is the ability to survive in the waterlogged and anoxic soil and ability to tolerate saltwater (Hogarth 2015), differences in elevations will cause different frequencies of inundation and salinity, which may control the mangrove diversity. Thus, the distribution of mangrove species will be varied based on species tolerance to the inundation and salinity from aerial root architecture of each mangrove species (Ellison 2005). Study by Chowdhury (2016) concluded that increased water salinity accentuates the abundance of salt-tolerant species with physiological and phenological such as *A. marina* and decreased abundance of salt-sensitive mangroves such as *R. mucronata*.

Table 2. List of major components, minor component and associate species of mangrove found in Mimika District, Papua, Indonesia

Family	Species	Growth form	Classification ^a
Arecaceae	<i>Nypa fruticans</i> Wurm	Rhizomatous palm	1*
Avicenniaceae	<i>Avicennia alba</i> Bl	Tree	1
Avicenniaceae	<i>Avicennia marina</i> (Forssk.) Vierh	Tree	1*
Avicenniaceae	<i>Avicennia officialis</i> L.	Tree	1*
Avicenniaceae	<i>Avicennia lanata</i> Ridley	Tree	1
Combretaceae	<i>Lumnitzera littorea</i> Voigt.	Tree	1*
Combretaceae	<i>Lumnitzera racemosa</i> Willd	Tree	1
Combretaceae	<i>Lumnitzera rosea</i> (Gaud.)	Tree	1
Meliaceae	<i>Xylocarpus granatum</i> Koen.	Tree	1*
Meliaceae	<i>Xylocarpus moluccensis</i> (Lamk) M. Roem.	Tree	1*
Rhizophoraceae	<i>Bruguiera cylindrica</i> (L.) Bl.	Tree	1
Rhizophoraceae	<i>Bruguiera gymnorhiza</i> (L.) Lam	Tree	1*
Rhizophoraceae	<i>Bruguiera parviflora</i> (Roxb.) W. & A. ex Griff.	Tree	1*
Rhizophoraceae	<i>Bruguiera sexangula</i> (Lour.) Poir.	Tree	1*
Rhizophoraceae	<i>Ceriops tagal</i> C.B. Rob	Tree	1*
Rhizophoraceae	<i>Rhizophora apiculata</i> Blume	Tree	1*
Rhizophoraceae	<i>Rhizophora mucronata</i> Lam	Tree	1*
Rhizophoraceae	<i>Ceriops decandra</i> (Griff.) Ding Hou	Tree	1
Rhizophoraceae	<i>Rhizophora stylosa</i> Griff.	Tree	1
Sonneratiaceae	<i>Sonneratia alba</i> J.E. Smith.	Tree	1*
Sonneratiaceae	<i>Sonneratia caseolaris</i> (L.) Engl.	Tree	1
Acanthaceae	<i>Acanthus ilicifolius</i> L.	Shrub	2
Acanthaceae	<i>Acanthus volubilis</i> Wall.	Shrub	2
Bignoniaceae	<i>Dolichandrone spathacea</i> (L.f.) K. Schum.	Tree	2
Bombacaceae	<i>Camptostemon schultzei</i> Masters.	Shrub/tree	2*
Ebenaceae	<i>Diospyros papuana</i> Valetton ex Bakh.	Tree	2
Euphorbiaceae	<i>Excoecaria agallocha</i> L.	Tree	2*
Myrsinaceae	<i>Aegiceras corniculatum</i> (L.) Blanco	Shrub/tree	2
Pteridaceae	<i>Acrostichum aureum</i> L.	Fern	2
Rubiaceae	<i>Nauclea papuana</i> Versteeg	Shrub	2
Rubiaceae	<i>Scaphiphora hydrophyllacea</i> Gaertn. f.	Shrub	2
Arecaceae	<i>Metroxylon sagu</i> Rottb.	Palm tree	3
Aizoaceae	<i>Sesuvium portulacastrum</i> (L.) L.	Herb	3
Amaryllidaceae	<i>Crinum asiaticum</i> L.	Lily	3
Anacardiaceae	<i>Camposperma brevipetiolata</i> Volk	Tree	3
Anacardiaceae	<i>Rhus taiensis</i> Guill	Tree	3
Apocynaceae	<i>Calotropis gigantea</i> (L.) R.Br.	Fern	3
Arecaceae	<i>Gulubia costata</i> (Becc.) Becc.	Palm tree	3
Arecaceae	<i>Oncosperma tigillarum</i> (Jack.) Ridl.	Palm tree	3
Asclepiadaceae	<i>Finlaysonia maritima</i> (Blume) Backer ex K. Heyne	Tree	3
Asteraceae	<i>Pluchea indica</i> (L.) Less.	Shrub	3
Boraginaceae	<i>Cordia subcordata</i> Lamarck	Tree	3
Calophyllaceae	<i>Calophyllum innophilum</i> L.	Tree	3
Calophyllaceae	<i>Calophyllum soulattri</i> Burm. f.	Tree	3
Casuarinaceae	<i>Casuarina equisetifolia</i> L.	Tree	3
Convolvulaceae	<i>Ipomoea pes-caprae</i> (L.) R.Br.	Vine	3
Convolvulaceae	<i>Ipomoea pes-caprae</i> (L.) Sweet.	Vine	3
Combretaceae	<i>Terminalia catappa</i> L.	Tree	3
Fabaceae	<i>Canavalia maritima</i> Thouars.	Herb	3
Fabaceae	<i>Derris trifoliata</i> Lour	Tree	3
Fabaceae	<i>Inocarpus fagiver</i> (Parkinson ex Zollinger) Fosberg	Tree	3
Fabaceae	<i>Intsia bijuga</i> (Colebr.) Kuntze	Tree	3
Fabaceae	<i>Millettia pinnata</i> (L.) Panigrahi	Tree	3
Fabaceae	<i>Pongamia pinnata</i> (L.) Pierre	Tree	3
Fabaceae	<i>Derris trifoliata</i> Lour.	Tree	3
Goodeniaceae	<i>Scaevola taccada</i> (Gaertn.) Roxb.	Shrub	3
Lamiaceae	<i>Clerodendrum inerme</i> (L.) Gaertn.	Shrub	3
Lamiaceae	<i>Vitex ovata</i> Thunb.	Shrub	3
Lecythidaceae	<i>Barringtonia asiatica</i> (L.) Kurz.	Tree	3
Malvaceae	<i>Talipariti tiliaceum</i> (L.) Fryxell	Tree	3
Malvaceae	<i>Thespesia populnea</i> (L.) Soland. ex Correa	Tree	3
Malvaceae	<i>Heritiera littoralis</i> Aiton	Tree	3
Moraceae	<i>Ficus microcarpa</i> L. fil	Tree	3
Myristicaceae	<i>Myristica fatua</i> var <i>Papuana</i> dei Swaiem	Tree	3
Pandanaceae	<i>Pandanus tectorius</i> Sol.	Shrub/tree	3
Tetramelaceae	<i>Octomeles sumatrana</i> Miguel	Tree	3

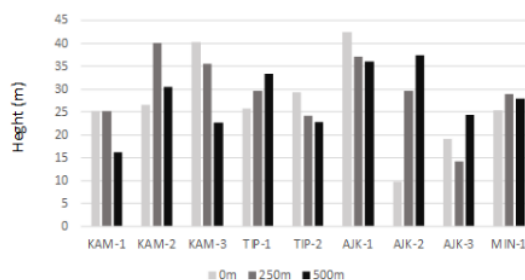
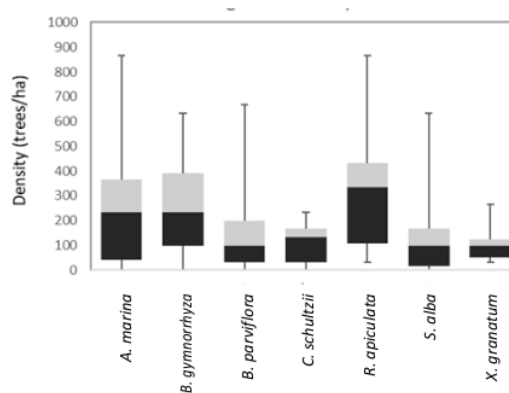
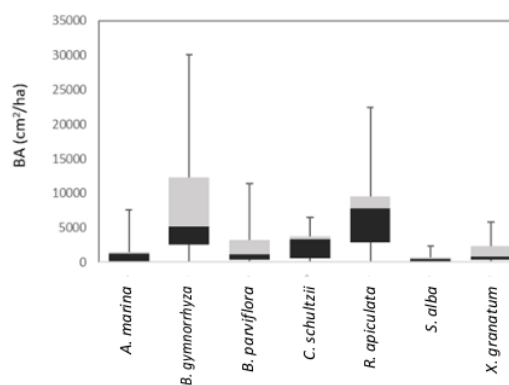
Table 3. Density, Shannon-Wiener diversity index (H') and evenness index (J') of the mangrove forest in Mimika District, Papua, Indonesia

Location	Location	Tree density (tree ha ⁻¹)	H'	J'
KAM-1	Kamora Estuary	722 ± 96	0.82 ± 0.16	0.86 ± 0.10
KAM-2	Kamora Estuary	577 ± 168	0.88 ± 0.31	0.77 ± 0.05
KAM-3	Kamora Estuary	689 ± 107	0.66 ± 0.15	0.70 ± 0.16
TIP-1	Tipuka Estuary	711 ± 107	0.76 ± 0.52	0.49 ± 0.24
TIP-2	Tipuka Estuary	878 ± 204	1.07 ± 0.36	0.81 ± 0.19
AJK-1	Ajkwa Estuary	767 ± 88	1.19 ± 0.14	0.92 ± 0.06
AJK-2	Ajkwa Estuary	711 ± 126	0.94 ± 0.45	0.61 ± 0.42
AJK-3	Ajkwa Estuary	1345 ± 414	1.12 ± 0.47	0.80 ± 0.05
MIN-1	Minajerwi Estuary	756 ± 301	0.62 ± 0.09	0.73 ± 0.25

The evenness index (J') ranged from 0.61-0.92, which is classified as high. The highest evenness index (0.92) was recorded at AJK-1 in the Ajkwa Estuary, whereas the lowest (0.49) was found at TIP-1 in the Tipuka Estuary.

The canopy heights of the mangrove trees are shown in Figure 3. The tallest mangroves were found at AJK-1 at 0 m (43 m) and the shortest at AJK-2 at 0 m (10 m). AJK-1 also had the highest average canopy height of 39 m. Nevertheless, there was no consistent pattern in height difference at 0, 250, and 500 m. In five of the nine locations, the mangroves nearest the shoreline were the shortest, probably because they were generally the youngest trees. Study from Lugo & Medina (2014) found that the tree height decreases following environmental gradients from low to high salinity, low to high wind speed, high to low air temperature, high to low nutrient availability, and high to low rainfall.

Figures 4 and 5 provide the plots for the densities and basal areas of the most dominant species in the study area. The highest density was recorded for *R. apiculata* with a median of 333 trees ha⁻¹ followed by *A. marina*, *B. gymnorhiza*, and *C. schultzei*. In contrast, *B. parviflora*, *S. alba*, and *X. granatum* were found to be the least dense. For the basal area, *R. apiculata* and *B. gymnorhiza* were found to have among the highest with median basal areas of 7,853 cm² ha⁻¹ and 5,201 cm² ha⁻¹ respectively. Trees with a lower basal area were *C. schultzei*, *B. parviflora*, *S. alba*, *A. marina*, and *X. granatum*.

**Figure 3.** Average canopy height of the mangrove trees in Mimika District, Papua, Indonesia Vegetation composition and structure**Figure 4.** Mangrove density of dominance species of the mangrove forest in Mimika District, Papua, Indonesia**Figure 5.** Basal area of dominant species of mangrove forest in the Mimika Region, Mimika District, Papua, Indonesia

Species importance value

Based on the Species Importance Values (SIV), *R. apiculata*, *B. gymnorhiza*, and *A. marina* are the most dominant species. These SIV are 121±58 for *A. marina*, 119±63 for *R. apiculata*, and 115±61 for *B. gymnorhiza*. Both *R. apiculata* and *B. gymnorhiza* are found at all locations. The SIV of each sampling location is illustrated

in Figure 5. Both *R. apiculata* and *B. gymnorrhiza* are dominant in all locations excluding AJK-3, which is dominated by *A. marina* and *S. alba*.

The dominance of few mangrove species across all sampling locations can result in favorable conditions to those dominant species. A study in Sri Lanka by Cooray (2021) showed that the main drivers of the variability in mangrove vegetation structure and composition were soil salinity and nutrients, which is consistent with study by Barick et al (2014) where salinity is the main factor influencing mangrove community zones. Since the mangrove forest community extends about 20 km inland from the coastline, this fast mangrove forest may provide more homogenous environmental conditions which resulting in dominance for only few mangrove species. The high and dense tree canopy may be resulting less light penetration to the mangrove floor which may limit mangrove colonization by other species (Lettow 2014).

Mangrove zonation

Mangrove zonation in Mimika District from swamp forest down to the coastline, a 20 km stretch of land, is shown in Figure 7. Mangrove areas can be classified into four tidal zones: low, medium-low, medium-high, and high. This classification is based on the elevation data obtained by LIDAR in which the low tidal zone is <0.5m; the medium-low tidal zone is 0.5-1.5 m; the medium-high tidal zone is 1.5-2 m; and the high tidal zone is >2 m. Using the 2019 Tide Table provided by www.pushidrosal.id, the estimated inundation of the low tidal zone is >4,800 hr.yr⁻¹ or >55% of the year (8,760 hours); 1,600-4,800 hr.yr⁻¹ for the medium-low tidal zone; 600-1,600 hr.yr⁻¹ for the medium-high tidal zone; and < 600 hr.yr⁻¹ for the high tidal zone.

Each tidal zone is dominated by one or two species. The low tidal zone, particularly the newly colonized area, is dominated by *A. marina* and *S. alba*. *R. mucronata*, which

are commonly found along riverbanks. A good representative example of this zone is AJK-3 in the seaward margin of the Ajkwa Estuary (see Figure 7) where *R. apiculata* followed by *B. gymnorrhiza* are the most dominant species. *B. parviflora* is widely distributed and can be found in three zones, (i.e., the medium-low tidal, medium-high tidal, and high tidal zones). The high tidal zone features low salinity and marks the point of transition of the mangrove forest into swamp forest. This zone is dominated by *N. fruticans*.

Discussion

A total of 66 species were found in this study comprising of 20 species of major mangrove components, 10 species of minor components and 36 species of mangrove associates. Other studies conducted in Papua have similarly found these same 20 major mangrove components species. Most mangrove associates are typically found in the landward margin of the mangal and often in non-mangal habitats such as rainforest, salt marsh, or lowland freshwater swamps. Previous research has recorded 11 species of mangrove trees at 2 sites in the Tipuka Estuary, Mimika (Kusmana et al. 1998, unpublished report; Ellison 2005). A study conducted in Bintuni Bay, West Papua recorded 28 true mangrove species representing 11 families (Yudha et al. 2021), while Lekitoo and Tambing (2018) only recorded 13 mangrove plant species belonging to 6 families in the same area.

The mangrove forest communities found in Mimika District are similar to those studied by Robertson et al. (1991) in Papua New Guinea who record 29 mangrove plant species comprising 3 major forest types in the delta, namely *Rhizophora-Bruguiera*, *Nypa*, and *Avicennia-Sonneratia*. According to Ellison (2005), the mangrove flora of southern Papua New Guinea consists of 32 mangrove species and 1 hybrid belonged to 15 genera and 13 families.

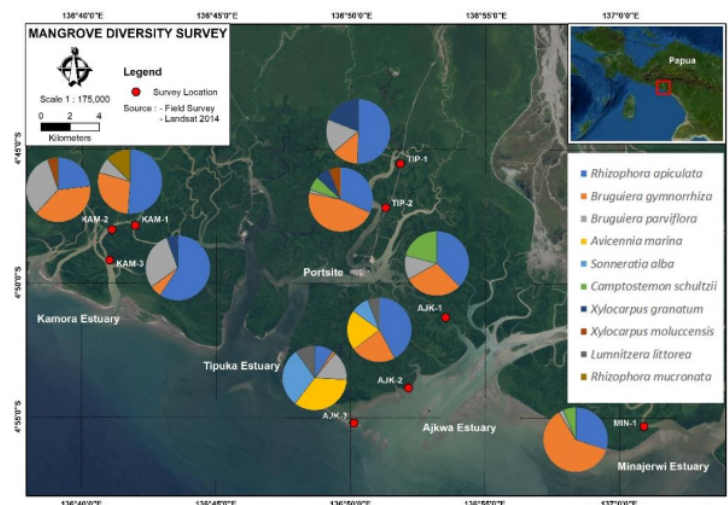


Figure 5. SIV of the mangrove forest in Mimika District, Papua, Indonesia

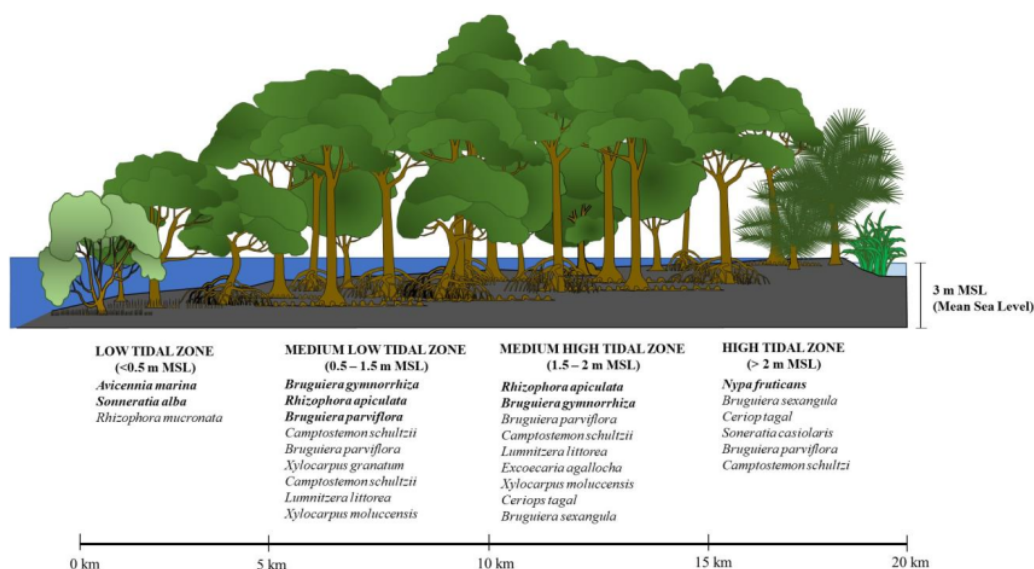


Figure 7. Mangrove zonation in Mimika District, Papua, Indonesia from the coastline until 20 km inland with dominant species (bold font is the dominant species)

The mangrove density of Mimika District ranges from 577-1,345 trees ha^{-1} , a bit higher than that found in Bintuni, which ranges from 372-544 trees ha^{-1} (Pribadi 1998). Other studies in Mimika report densities of 319-569 trees ha^{-1} (Kusmana et al. 1998). Mangrove density in the study area was much lower than in other mangrove areas in Indonesia, such as Segara Anakan, and Central Java (8,000 trees ha^{-1} , Hinrich et al. 2009), Lamongan and East Java (2553 trees ha^{-1} , Arif et al. 2019), Aceh Besar (1,200-3,200 trees ha^{-1} , Permatasari et al. 2018), and West Sumatra (900-1,450 trees ha^{-1} , Rizal and Anna 2020). However, the density values recorded here are comparable to those found in West Kalimantan, which range from 623-740 trees ha^{-1} (Nugroho et al. 2019). The lower mangrove density in Mimika reflects a more mature mangrove ecosystem and an absence of disturbance, which has allowed the mangrove trees to grow to their maximum height (see Figure 3). The study finds a mangrove tree height range of 9-42.5 m. This is consistent with previous studies, which report various average mangrove tree heights of 2.7-45 m (Brunskill 2004; Ellison 2005; Aslan et al. 2016). Taller mangrove trees, particularly *R. apiculata* and *B. gymnorrhiza*, were found in the medium tidal zone. The maximum height recorded for *B. gymnorrhiza* was 58 m and 59.3 m for *R. apiculata*. The highest tree recorded in this study (59.4 m) was *B. parviflora* found at KAM-2 in the Kamora Estuary. The typical diameter of the trees ranged from 30-50 cm with a maximum of 69 cm recorded for *R. apiculata*. Shorter mangroves (*A. marina* and *S. alba*) were mostly colonized in the newly-developed mud flats or at the riverbanks. Here, the maximum height of *A. marina* was 16 m, whereas *S. alba* was 14 m. Shorter mangrove species were also found at the riverbank, which was dominated by

R. mucronata.

The assumed maturity of the mangrove forest in Mimika is supported by the basal area measurements of 24-90 $\text{m}^2 \text{ha}^{-1}$. These basal area measurements are within the range of previous research conducted in Bintuni, Papua, where basal areas have been found to range from 28.3- 36.9 $\text{m}^2 \text{ha}^{-1}$ (Pribadi 1998), and an existing study of Mimika (22.9-33.6 $\text{m}^2 \text{ha}^{-1}$; Kusmana et al. 1998). They are also consistent with data from Galley Reach, Papua New Guinea (30 $\text{m}^2 \text{ha}^{-1}$; Paijmans and Rollet 1977). Basal area measurements in Papua are higher than those found in the mangrove forests of some other regions in Indonesia, such as in Segara Anakan and Java (19.4 $\text{m}^2 \text{ha}^{-1}$; Hinrich et al. 2009) and the Kayan-Sembakung Delta in North Kalimantan (44.5 $\text{m}^2 \text{ha}^{-1}$; Seftianingrum et al. 2020). The basal area measurements recorded in this study are also higher than in the mangrove forests of the Andaman Islands, India (30.8-59.6 $\text{m}^2 \text{ha}^{-1}$; Kiruba-Sankar 2018) and the Sundarban Delta, India (0.4-13.4 $\text{m}^2 \text{ha}^{-1}$; Sreelekshmi 2020).

The high basal area is evidence that mangroves in Mimika are a pristine mangrove forest. Compared with another pristine forests such as pristine forest in Sarawak, Malaysia (Shah et al. 2016), mangrove forests in Mimika had higher diameters and three heights. The very minimum disturbance from human activity and less environmental disaster resulting mangrove species in this area can grow to maximum height.

The vast and healthy mangrove forest in Mimika, of a total area of 186,291 ha (Aslan et al. 2018), may have been enhanced by sedimentation. Sediment is the result of rainfall-driven erosion in the mountains, which creates large river catchments (Brunskill et al. 2004). The

mountains of Papua, with Puncak Java the highest elevation in the region at 4,884 m above sea level, have resulted from the rapid convergence of the Australian and Pacific plates (Baldwin et al. 2012). The combination of high elevation and high rainfall has resulted in high erosion, creating sediment deposition in coastal areas. These newly created soft-bottom sediments deposited in the estuary mouth have been rapidly colonized by a vast mangrove forest. Sedimentation is known to be a contributing factor of mangrove diversity and density (MacKenzie et al. 2016).

The maturity of the mangrove forest in Mimika might affect the dominance of some mangrove species and be responsible for the low Shannon-Wiener diversity index of 0.62-1.19. Mangrove diversity has been retarded because of the high level of canopy cover, which reduces light penetration to the mangrove floor, limiting colonization by other mangrove species. Several forest studies have concluded that the forest canopy affects understory light levels, impacting plant growth and survival, as well as diversity due to the effects of light competition between plants (Lettow 2014; Berrill et al. 2017). Among the locations studied here, the highest diversity index was found at AJK-3 in the Ajkwa Estuary (1.79). This location has the lowest average canopy cover compared with other locations because it is nearest the seaward zone where new colonization takes place. The average canopy height of this location is 19 m compared with the average height of all locations of 28 m. This data supports the assumption that a lower canopy height allows more light penetration, which, in turn, increases plant growth and natural succession. The high density in this seaward location (1,794 trees ha⁻¹) shows that new colonization occurs alongside the presence of some pioneer species such as *A. marina* and *S. alba*. Fajri et al. (2012) also identify *S. alba* as the most dominant species colonizing a new island in the Ajkwa Estuary.

The most dominant species at all locations are *R. apiculata* and *B. gymnorrhiza*, as seen in the Species Importance Values (SIV). Kusmana et al. (1998) also find both these dominant species in the same area. Kusmana et al. (1998) also record two community types of mangrove: the *B. Gymnorrhiza*-*C. schultzei*-*R. apiculata* community and the *B. cylindrica*-*R. apiculata* community, with *R. apiculata* having the highest density.

This study classifies the mangrove zones in Mimika based on seawater inundation as low, medium-low, medium-high, and high tidal zones with a diurnal tidal regime of 3.4 m. The only classification of mangrove areas in Mimika was previously made by Ellison (2005), who distinguishes five community distributions of mangrove, i.e., the seaward pioneer community at the lowest elevations, which is dominated by *Avicennia* and *Sonneratia*, the *R. stylosa*-*B. gymnorrhiza* dominated area at the south of the estuaries and outer bends of the rivers, the *B.* dominated area at slightly higher elevations, the *N. fruticans* area, and the mixed mangrove area on the margins of freshwater areas.

This study shows that in the low tidal zone, *A. marina* and *S. alba* are the dominant species. This is consistent

with many studies that have concluded that *A. marina* and *S. alba* have an adaptive mechanism that enables them to withstand higher salinity levels (Hasegawa et al. 2014; Almahasheer et al. 2016). Moreover, *R. apiculata* and *B. gymnorrhiza* are found to be dominant in medium-low and medium-high tidal zones. Both species appear to have a high tolerance of salinity. Salinity is the main factor influencing mangrove community zones and each mangrove species has different salinity tolerance (Barik et al. 2014). In this study, the species found to be the most adaptable to different inundation and salinity levels is *B. parviflora*. This species can be found in three zones, i.e., medium-low, medium-high, and high tidal zones. Using the classification regime proposed by van Loon et al. (2007), *Bruguiera* is found in normal high tide and spring high tide areas with a monthly flooding frequency of 2-45 times. The high tidal zones in the study area of this research are areas where the mangrove forest transitions to freshwater swamp or rainforest. Other *Bruguiera* genera, such as *B. sexangular*, are also found but at low densities as this zone is dominated by *N. fruticans*.

The study shows that the mangrove ecosystem in this part of Mimika is very rich in mangrove tree diversity. Due to the vast mangrove area in Mimika District, more detailed research is needed to further explore this magnificent mangrove forest in Papua, which is likely to be the most pristine and diverse mangrove forest in the world. The results of such research will be very valuable for sustainable mangrove resource management in Papua, Indonesia, which has mangrove forests covering a total area of almost 1.5 million hectares.

ACKNOWLEDGEMENTS

We would like to thank PT Freeport Indonesia for their support in conducting this study and the Mangrove Team in the Department of Marine Science, Faculty of Fishery and Marine Science, Universitas Diponegoro, for their involvement in collecting data in the field. Thank you also to Dr. Jurgenne Primavera and Dr. Tengku Zia Ulqodry for reviewing this manuscript and providing valuable inputs. The authors declare no competing interests.

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